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An investigation of the characteristics and performance of a direct injection crop sprayer

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AN INVESTIGATION OF THE CHARACTERISTICS AND PERFORMANCE OF A DIRECT INJECTION CROP SPRAYER

Submitted by Andrew John Landers for the degree of Ph.D of the University of Bath
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SUMMARY

A conventional crop sprayer, fitted with a direct injection system comprising three pumps which dispensed pesticide at a known rate into the waterflow to the nozzles underwent evaluation trials at the Royal Agricultural College, Cirencester.
Laboratory studies, using potassium permanganate, investigated the mixing effectiveness, response times, and accuracy due to changes in operating parameters. Results showed that pesticide concentration levels between nozzles were consistent, and remained consistent, over a period of time when the pump injected pesticide at a constant rate. This was supported by field trial evidence on weed and disease control.

The pump output was linear at varying dose levels when using water, although the viscosity of certain pesticides at particular temperatures will require the pump to be calibrated specifically for them. The pump responded quickly to changes in forward speed and dose level adjustments.

Field trials were carried out using pesticides on grass, fodder beet and cereals to assess the overall practicability of the system and the field importance of the delay in pesticide reaching the nozzles. The level of weed and disease control was as expected, comparable to that achieved by a conventional sprayer.

The advantages of direct injection sprayers in reducing pesticide use, operator contamination and environmental pollution are discussed.

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LIST OF ABBREVIATIONS AND UNITS

A.D.A.S	Agricultural Development and Advisory Service
B.A.A	British Agrochemicals Association
B.C.P.C	British Crop Protection Council
DIN	Deutsche Industrie Norm
EC	European Community
g	gramme
h	hour
ha	hectare
HSC	Health and Safety Commission
HSE	Health and Safety Executive
km	kilometre
kW	kilowatt
l	litres
lpg	liquified petroleum gas
m	metre
MAFF	Ministry of Agriculture, Fisheries and Food
mg	milligramme
min	minute
ml	millilitre
µg	microgramme
µm	micrometre
nm	nanometres
pto	power take off
SCAE	Scottish Centre of Agricultural Engineering

CHAPTER 1. INTRODUCTION

The agricultural industry is attempting to maintain profitability in the face of rising costs and low market prices by making better use of resources and cutting production costs.

Farmers and growers in Britain use substantial quantities of pesticides; in 1990 23,750 tonnes of active ingredients worth £413.5 million were applied, most of it to cereals, (BAA, 1991). Murphy (1991) estimated that pesticide costs can amount to 40% of the variable costs of production for winter cereals and 18% for potatoes in Eastern England. The average pesticide costs for farms are shown in Tables 1.1 and 1.2.

Apart from the cost, farmers are under other pressures when applying pesticides. The increasing public awareness of environmental pollution, along with concern about pesticide being applied on food crops has resulted in legislation to control pesticide use. During the period since 1980, there has been frequent legislation concerning operator safety and training, and pollution control. There is also legislation within the European Community that will affect all aspects concerning pesticide application, especially after 1993.

Since spraying of crops with various types of pesticide became a routine farm operation, the essentials of spraying are still much as they were in the infancy of spraying almost one hundred years ago. The methods in use have some shortcomings, there still being room for improvements in overall safety provision for operators; another is the need for large volumes of water to wash the equipment thoroughly, rinsate which then poses a disposal problem. An alternative to contaminating the sprayer tank with pesticide is the direct injection sprayer which is the subject of this thesis.

Pesticide application has become a fundamental part of agricultural production, and to be effective reliable equipment and trained operators are required. Current developments in electronics (coupled with a greater acceptance by farm staff) have led to a revised interest in the development of injection sprayers, in which electronics can be used to operate and monitor application.

Traditionally, farmers have used pesticides to 'blanket' spray the whole field. The advent of direct injection sprayers and computer based information systems will allow them to spot treat patches of weeds or diseased crop. Cussans et al (1987), suggests that many fields are treated at weed levels far lower than the economic threshold because of poor herbicide performance and differing infestation levels. The quantification of these risk elements would be a valuable practical step in rationalising pesticide use.

The components of an injection sprayer underwent evaluation trials at the Royal Agricultural College, Cirencester. This

thesis presents the results of an investigation into their operational performance.
Laboratory and field trials were used to investigate the accuracy of the injection pump, with a variety of pesticide types and at varying dose rates. The effectiveness of mixing pesticide and water in the mixing chamber were evaluated on a number of crops and compared with a conventional sprayer. The time taken for the pesticide to reach the first and last nozzle is of interest because of patch spraying (spot treatment) of weeds and any delay in pesticide reaching the boom results in an unsprayed area.

The injection system was used on a large arable farm to monitor mechanical and electronic reliabilty. A farm is a hostile environment for electronics and the controlling mechanism (controller) needs to be rugged to withstand any problems. The controller is sophisticated yet is designed to be simple to use and its ease of operation will be assessed. The farm trial is intended to demonstrate the operational advantages and draw attention to problems that may arise, such as pesticide container handling and excessive maintenance requirements.

Finally, a computer programme has been designed which will evaluate any increases in sprayer workrate following the introduction of an injection sprayer onto a number of large farms.

Table 1.1 **Average pesticide costs (£/ha) for field scale vegetables in Eastern England**

Crop	1986/87	1987/88	1988/89	1989/90
Carrots	134	228	280	156
Onions	193	213	264	251
Parsnips	163	353	359	514
Brussels Sprouts	189	130	227	150

Source: Report on farming in the Eastern Counties of England 1988/89 and 1989/90. Murphy (1991)

Table 1.2 **Average pesticide costs (£/ha) for arable crops in Eastern England 1989/90 (1988/89)**

Farm Size & type ha	Crop: winter wheat	winter barley	potatoes	sugar beet	oilseed rape
40-400 upland	103.8	76.6	190.7	126.4	77.7
	(90.7)	(70.2)	(87.3)	(115.0)	(70.5)
40-400 mixed	103.3	89.0	139.3	171.6	54.3
	(92.9)	(77.4)	(75.8)	(116.3)	(55.8)
40-400 fen	92.0	67.8	291.9	141.4	74.8
	(88.4)	(62.8)	(303.0)	(125.8)	(66.2)

Source: Report on farming in the Eastern Counties of England 1988/89 and 1989/90. Murphy (1991)

CHAPTER 2. LITERATURE REVIEW

2.1 BACKGROUND

An awareness of increasing environmental pollution and the need for greater operator safety, along with falling profit margins, has led to more consideration of accuracy, timeliness and safety precautions.

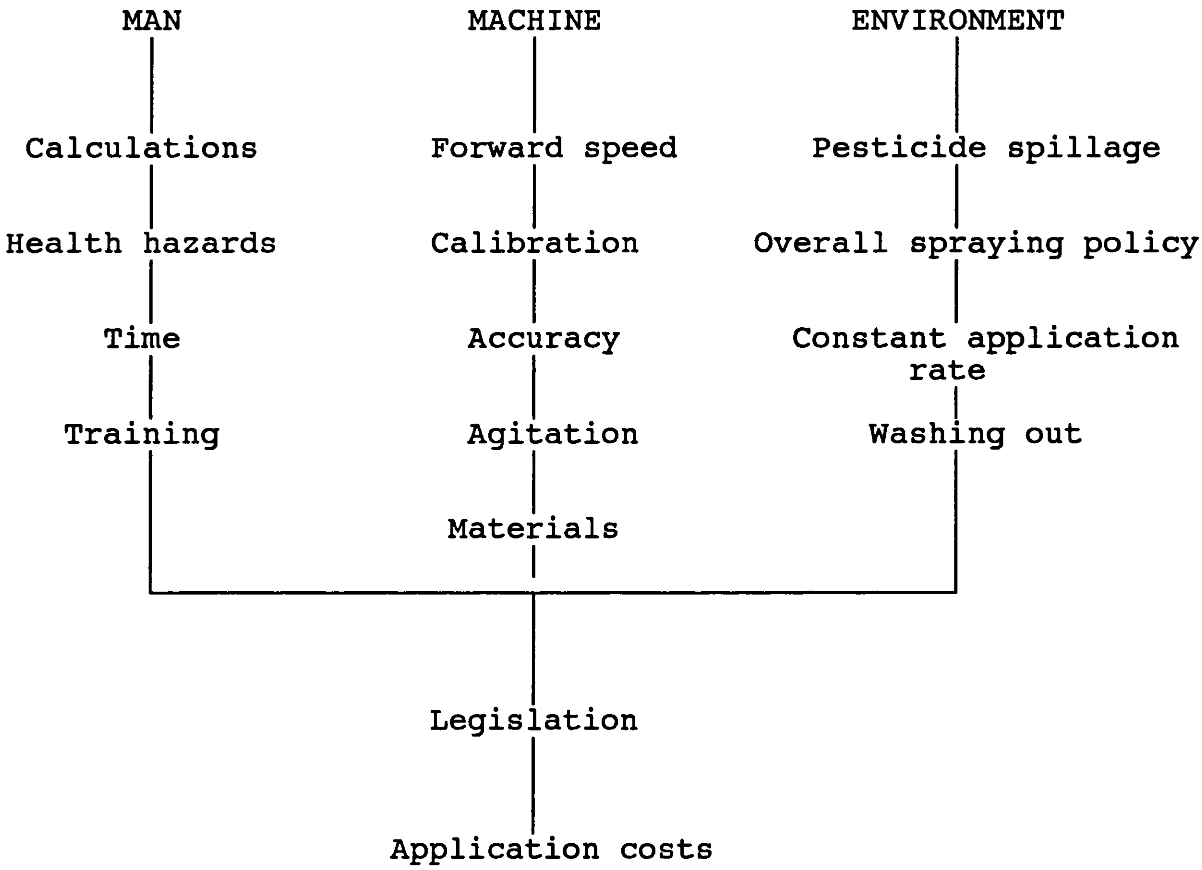
Conventional crop sprayer design has altered little during the last 50 years, and it is only in the last decade that major advances have reached farm level. Although equipment is now lighter, corrosion resistant and more efficient (Stephens, 1982), it relies upon the same principles of operation as the original sprayers of the late nineteenth century.

There are many problem areas associated with conventional crop sprayers, as outlined in Figure 2.1. The problems concerning man and his machine working within the environment are inter-dependent.

2.1.1 Man

The sprayer operator has many calculations to perform regarding tractor forward speed, application rate, water volume, and nozzle output. The amount of pesticide to add to the water tank along with tank mixes of different amounts of pesticide need to be calculated within the framework of the label recommendation. On large farms the operator may have a large area to spray and may be under time pressures to carry

Figure 2.1 **Problems associated with a conventional crop sprayer**



out the task as quickly as possible. The better farms will provide the operator with a worksheet detailing all the application information per field. The operator may be mentally stressed to ensure the correct quantity is applied.

The main hazards to health, which include contamination, particularly when decanting or measuring concentrate pesticides; operators have to unscrew the transit cap, pierce a foil seal and decant the product. In addition, many sprayers require operators to climb onto the machine while holding the concentrate to reach the tank opening in which to pour the pesticide.

Dubelman et al (1982), Abbott et al (1987) and Grover et al (1988) studied dermal deposition and found the highest risk was during loading and mixing pesticides rather than during application. Of the 16 agricultural workers affected by pesticides in incidents investigated by the HSE (1990), one operator had pesticide splashed into his eyes when he accidentally opened a valve at the end of a transfer pipe between the mixing tank and the crop sprayer.

Pesticide can enter the body in three ways, by absorption through the skin, by inhalation and by ingestion. The Regional Poisoning Treatment Centre at the Royal Infirmary in Edinburgh, (Proudfoot and Dougall, 1988), monitored acute poisoning incidents involving pesticides over six years. There were seven work-related accidents with herbicides, insecticides and fungicides. Two were the result of irresponsibility, one the failure to apply common sense, one failed to comply with safety instructions and one failed to maintain spray equipment correctly. The last two incidents were caused by a breakdown in communication, inadequate training or poor supervision and working practices.

The Edinburgh study showed that cases of acute poisoning were rarely reported, and to help general practitioners the Health and Safety Executive commissioned a research project in February 1991, (HSE, 1991a), in which a 'Green Card' will provide doctors with a simple means of reporting pesticide poisoning cases. A 24 hour telephone number for help is also provided on the card. In the State of California, where pesticides are used intensively and on a very large scale, all pesticide related illnesses have had to be reported since 1973, (Kilgore and Akesson, 1980).

Her Majesty's Agricultural Inspectorate confirmed 16 cases of acute pesticide poisoning amongst farmers and farm workers during 1989-90, (HSE, 1990) and 18 cases in 1990-91, (HSE, 1991b). These figures are very low in relation to the estimated 117,500 pesticide users although there is some evidence that users do not report temporary symptoms unless closely monitored.

A joint trade union report on pesticide usage, T.U. (1986), warned that 50% of a sample of 297 responses to a questionnaire had suffered from headaches, sickness and sore throats, the classic symptoms of chronic, low level exposure to toxic chemicals. The report stated that more than 80% of the respondents were supplied with protective clothing.

The operator is at risk from splashes of dilute pesticide during the washing out of the sprayer, when boom folding and from spray drift, according to Turnbull et al (1985) and Landers (1989a). The time taken to measure and decant pesticides, and for adequate washing out of the pesticide containers and the sprayer tank after use is expensive and may well encroach upon the time available for spraying. If the operator hurries these tasks then the chance of contamination increases.

Dermal and respiratory exposure of operators applying 2,4-D with five types of application machine was studied by Abbott et al (1987). Tractor powered conventional sprayers presented less dermal risk than knapsack sprayers and as expected the highest risk was during loading and mixing pesticides rather than during application. Similar results were found by Dubelman et al (1982) who showed that dermal deposition on the hands during tank filling exceeded all other dermal values by 200-fold. Grover et al (1988) found that inhalation exposure was less than 2% of the total body exposure, the remainder being dermal exposure, of which 80 to 90% was on the hands and so hand protection must remain a major concern.

The potential for excessive operator exposure must be viewed as a significant concern when operators are using recycled rinsewater, according to Hock (1987). Recycled tank rinse-water contains pesticide and its routine use is one of the suggestions made for the safe disposal of tank washings in the Code of Practice, (MAFF/HSC, 1990), section 2.1.3.

Engineering controls are an effective means of reducing exposure. For example, Lunchick et al (1988) found that dermal exposure for the operator in an enclosed tractor cab during conventional spraying was only one-sixth the exposure for the operator with an open cab. With an air-blast sprayer, use of an enclosed cab reduced the exposure even more, to a mere 1/30 of the previous value.

A survey for BCPC by Gilbert et al (1986) highlighted several areas of concern with pesticide application. Poor container design, deficiencies in label information, confusion regarding the wearing of protective clothing and inadequate training of sprayer operators were some of the findings. Knaak et al (1980) and Cowell et al (1987) concluded that operators using the correct protective clothing and a well designed closed transfer system will experience negligible exposure to pesticides.

The key problem to transfer design has been lack of standardisation of container openings, (Rutz, 1987), but in Europe the pesticide manufacturers group have chosen 63mm ASTM thread on packs of 5 litres or more and 45mm on smaller packs. Recent developments, including wide neck container openings to reduce glugging and handles large enough to be gripped by a large gloved hand have reduced the exposure risk concluded Gilbert (1989). The Code of Practice, MAFF/HSC (1990) recommends the use of engineering controls as the first priority to limit operator exposure. Protective clothing is a last resort.

Brazelton and Akesson (1987) showed that the number of pesticide related illnesses amongst mixer/loader workers in California decreased by 50% after the introduction of closed transfer systems. The Californian Department of Food and Agriculture adopted regulations in 1974 which required employers to provide employees with closed transfer systems for transferring Toxicity Class One pesticides and rinse solutions. Knaak et al (1980) and Cowell et al (1987) investigated pesticide levels in the blood and urine of mixer/loaders using closed transfer and open loading methods. Negligible exposure exists while using well designed closed transfer systems. American transfer systems use sealed suction probes, container puncturing or gravity operation. Appendix D details Californian legislation, criteria for closed transfer design and various types of transfer system.

The European pesticide manufacturers group commissioned the Battelle Institute to develop a closed transfer system, (Lavers, 1989) which uses a frame to invert the pesticide container. The pesticide manufacturer, Schering Agriculture, have devised a closed transfer system which uses spears to puncture the containers, (Southcombe et al, 1990). Miller (1990) concluded that significant commercial and development activity will result in new systems in the UK in the near future.

Operator training of all involved in the use of pesticides, besides being a legal requirement under the Code of Practice, (MAFF/HSC, 1990), should not only ensure that the correct dose is applied at the correct time but that the operator is fully aware of the most hazardous parts of the spraying operation and knows how to minimise his personal exposure.

In less well educated societies, guidance, understanding and surveillance of safe pesticide use are not easily attained according to Goulding (1983). Mabbett (1990) shared the same sentiments, suggesting the greatest potential for harming people who handle pesticides is now occurring in 'developing' countries because this is where the market is increasing but the infrastructure is less advanced. Where education is limited and workers may neither read nor understand the language of the label other means are necessary for communicating the essential facts about safety. For example, pictures are a vital form of communication with the migrant workforce in California, and Porter and Stimmann (1988) developed slide, storyboard and video sets for instructing Mexican workers in the safe use of pesticides using simple but unambiguous picture stories.

2.1.2 Machine

To ensure the correct application rate most sprayers must be driven at a constant speed although changing topography makes this difficult to attain and therefore several methods of controlling flow rates at varying speeds using electronics have been developed. Automatic flow controllers that use butterfly control valves to restrict flow can be used but these affect the spray pattern at the nozzles, resulting in non-uniform application.

Even when sprayers are calibrated regularly their accuracy cannot always be relied on. For example, surveys in U.S.A found inaccurate calibration of the sprayer due to incorrect nozzles and forward speed and errors in pesticide/diluent measurements. Rider and Dickey (1982) carried out a survey of 152 operators in Nebraska and found only one in four were applying pesticides within 5% of the estimated application rate. 20% of operators in Iowa and Ohio were applying pesticides within 5% of the intended rate; of the remainder, 44% over-applied and 56% under-applied, according to a survey by Ozkan (1987). 140 operators in Nebraska were investigated by Grisso et al (1988) and they found only 30% were applying pesticides correctly. Tank mix errors occurred with 19% of operators. A survey in Australia by Combellack (1984) showed similar results.

A survey by ADAS (1976) in England showed that 46% of operators had errors in excess of 10% of application rate.

Over half the operators interviewed had received no instruction on pesticide application. The introduction of the Food and Environment Protection Act, Part 11, 1985 along with the Code of Practice, MAFF/HSC (1990) has resulted in the requirement to train operators in the safe use and handling of pesticides along with the safe operation of application equipment. At the end of December 1990, 70,000 operators had received instruction under the auspices of the Agricultural Training Board, (Howard, 1991) and 50,000 certificates of competence issued to candidates who were successful in tests organised by the National Proficiency Tests Council.

Sprayer Clinics have been held in North America and in England. Farmers are encouraged to bring their sprayers for mechanical inspection. DuPont Company inspected 150 sprayers in North America, (Gerling, 1985), and found only 33% were within 10% of intended application rate - 60% were under-applying. A combination of inaccurate speeds, worn nozzles, unsuitable filters and inaccurate gauges caused the problems. Of 54 sprayers tested in England during 1989/90, Patchett (1990) found 44% had worn nozzles, 26% had inaccurate pressure gauges and 13% were operated with inaccurate tractor proof meters. The pesticide manufacturer Ciba-Geigy and pesticide distributor Willmott Crop Protection held clinics in Southern England, (Patchett, 1986), and found broadly similar results. 50% of sprayers had inadequate filtration, 65% of the 1718 nozzles tested were more than 10% inaccurate and of the 65 pressure gauges tested, 5 were broken.

According to a report in the newspaper, La France agricole, (Roelants du Vivier, 1988), 'the Albu company recently organized a three day testing session in Brie, France, during which farmers could have their nozzles tested for wear. More than 4000 invitations had been sent out and the event well publicized. Over the entire three days only 150 people turned up.'

The above survey and clinic results show how badly maintained are many sprayers and how untrained their operators. The Agricultural Training Board courses will address part of this problem but perhaps a compulsory sprayer testing scheme should be introduced as has been done in parts of Scandinavia and Germany.

Agitation of tank contents is essential to prevent stratification, especially on long farm tracks. However, excessive agitation which can cause frothing must be avoided. The correct timing of introducing an adjuvant into a tank is also important to prevent frothing. Roelants du Vivier (1988) in a written answer to a question to the Commission of the European Communities described the surfaces of country roads in France that were occasionally stained, sometimes blue or yellow, sometimes other colours, caused by passing crop sprayers whose tanks are dripping with froth overflowing from the filling openings. Children may be attracted by the pretty coloured froth with possibly serious consequences.

Sprayers can be constructed so as to reduce operator contamination but a report by HSE (1986) drew attention to the fact that the majority of crop sprayers exhibited unsatisfactory safety and ergonomic features relating to operator exposure to pesticides. Although the report concluded that sprayer manufacturers are willing to improve the design of sprayers, a review of 1991 sprayers shows that some manufacturers still expect operators to climb narrow steps, without hand holds, to obtain access to the filling hole on the top of sprayer tanks. Certain manufacturers supply low level induction bowls only as optional extras, whereas the fitting of a simple pesticide transfer device would seem a necessity to reduce potential contamination.

2.1.3. The environment

Pesticide spills during the filling of sprayers, which may result in crop damage and cause point source pollution and financial loss can be prevented by using closed transfer systems, section 2.1.2 above.

The use of an overall or blanket spraying policy can result in a waste of pesticide and therefore also a waste of money. When conventional sprayers use a tank mix of two or more pesticides, the operator has to apply all the products to the whole of the sprayed area; the operator is unable to select individual pesticides as and when required, e.g. for patches of different weed species or disease.

With conventional spraying methods a constant speed is required to obtain the correct application rate. There are certain times when an adjustment in application rate may be required, e.g. a heavy or light infestation of weeds. Some operators change forward speed to alter application rate, but problems of boom bounce and yaw can arise when forward speeds are increased.

A substantial proportion of pesticide applied conventionally is not deposited on the target but is wasted. Some of this loss arises from drift, but most is lost to the ground. Both types of loss constitute a potential environmental hazard, (Cooke et al, 1986). Careless overspraying of ditches, run-off from washing down areas and spillages are amongst the many sources of pollution. According to BAA (1990), ground-water pollution is determined by a number of factors such as the nature of the chemical and the amount applied along with the method of application, soil management and the nature and structure of the soil.

According to Lees and McVeigh (1988), Otter (1988) and the Water Authorities Association (1988) a number of agricultural pesticides have been detected in water supplies. According to the BMA (1990) many common pesticides have been detected, generally at very low levels, in water supplies. They include several triazines, mecoprop, MCPA, 2,4-D and MCPB. Sixteen pesticides were each detected above the EC MAC for a single pesticide. Atrazine and simazine are widely used by British Rail for total weedkilling on very porous railtracks, circumstances that would be expected to encourage leaching into groundwater.

The EC Directive (1980) sets Maximum Admissable Concentrations (MACs) of 0.1 microgram per litre (ug/l) for any individual pesticide and 0.5 ug/l for the total of all pesticides in drinking water. Hance (1989) warns that the Directive does not address the problems involved in deciding whether or not an observation close to this limit represents a 'true' residue nor does it provide much guidance on suitable sampling methods. There is a need for agreed protocols for obtaining and interpreting information on the possible presence of pesticides in potable water.

Because of these and other problems in interpreting the data from analysis it was suggested by Johnen (1990) that the quasi-zero value for all pesticides set by the EC Directive should be reconsidered and replaced by a concept of establishing individual values of each pesticide, based on the toxicological data available for that pesticide.

85% of total water resources in the U.S. are in the form of groundwater aquifers and this water provides drinking water for about 50% of the population. Groundwater contamination in North America, by domestic and industrial wastes from point sources, such as hazardous waste sites and illegal dumping, has created a great deal of attention (Wilkinson, 1991). Agricultural pesticides entering groundwater are likely to represent a relatively minor source of pollutants entering groundwater.

In Britain, a research report commissioned by the Department of the Environment (1988) concluded that although agricultural activities are a source of contamination, their relative importance has not yet been firmly established. The increasingly common occurrence of pesticides in groundwater, in conjunction with legally binding low MAC levels, is a cause for serious concern. The report gave priority recommendations for research into the effect of land use change and agricultural practice on pesticides in groundwater. Sophisticated equipment has enabled the detection of minute traces of pesticide residue and the rate of advance in analytical techniques will soon result in the ability to trace just a few molecules of pesticide in a sample of water.

Fawell (1991) proposed a compromise. His suggestion was to maintain the current standard for drinking water but allow the fall back position that if pesticides are found in drinking water, provided there is no threat to health, supply may continue, with suitable monitoring while action is taken to prevent further contamination at source. This approach will only work if the manufacturers and users are prepared to play their part in seeking ways to reduce contamination.

Farmers' assessments of different kinds of risk within a farm management strategy are a trade off with profitability according to Lowe et al (1990). Whilst many farmers expressed strong concern over environmental and personal health hazards, financial factors were more important; many farmers prefer to run the risk of detection than invest in high cost pollution technology. A linear programme model was developed by Bretas and Haith (1990) to determine an income-maximising set of management activities for a cash-crop farm subject to groundwater quality standards for pesticide contamination. Pesticide leaching coefficients for the model were estimated by a simulation model for pesticide movement through the root zone. Farm management data was collected via a series of farm management surveys and a database developed containing farm cropping programmes and farmers' incomes. The research model compared the levels of crop production and income with the optimum use of pesticides. The results indicated that a trade-off between farm income and groundwater quality may be significant.

Regular washing out of a crop sprayer is necessary to prevent build up of deposits or carry over of injurious products to another crop. Taylor et et al (1988) considered the problem of decontaminating a small 600 litre sprayer. The degree of cleaning will depend on the product being used. Thorough cleaning using the method outlined in the then proposed Code of Practice, MAFF (1988), took in excess of one hour, used 1500 litres of water, resulting in 5.2 ml of pesticide active ingredient remaining.

The Code of Practice, MAFF/HSC (1990), suggests that the volume of washings produced when cleaning out equipment can be reduced significantly by using an efficient flushing system. Researchers at SCAE developed the Rotaflush, a spinning disc for inserting into the sprayer tank to enable cascading water to flush the tank. Jeffrey (1991) conducted trials using chelated manganese and found that flushing twice, each of two minutes duration, using 30 litres of water, resulted in 1.06% of the original concentration remaining. Trials using pesticides would show interesting results as Taylor et al (1988) states that 83.6% of remnants were found in the pump, controls and pipework on a 600 litre sprayer and only 16.4% in the tank.

The problem of pesticide waste from tank washing is addressed by the Code of Practice, (MAFF/HSC, 1990). The storage of waste in suitable containers is recommended prior to being used as the diluent for further applications or for collection by a waste disposal contractor. Alternatively, contaminated water may be applied to the treated crop, recognising that the efficacy of the previous application of pesticide may be impaired. The time taken to rinse out the sprayer and return to the headland of the field one has been spraying could take a long time and therefore be expensive in labour costs and missed spraying opportunity. The operation of rinsing out a sprayer tank with a water hose is putting the operator at risk from splashes of pesticide.

Conventional tank rinsing, unless performed thoroughly can result in carry-over of pesticide to the next crop. BCPC (1986) noted in its 1985 Annual Review of Herbicide Usage that a minute amount of a herbicide as a contaminant in a subsequent spray could severely damage a susceptible crop. Its recommendation was that farmers should be made aware of the dangers of inadequate washing out. Gittus (1989) had been spraying the herbicide metsulfuron-methyl + thifensulfuron-methyl (Harmony M) on spring barley. The sprayer was washed out, following manufacturers instructions, using a proprietary tank cleaner - Allclear. The sprayer was then used to spray phenmedipham (Betanal E) on sugar beet. Sprayer residues resulted in the total loss of 2.8ha of beet. Growers also need to be very careful how they dispose of tank washings; which must be done in accordance with the Code of Practice, MAFF/HSC (1990).

60% of Louisiana's 190 aerial applicators used waste water recycling following the introduction of legislation to prevent the contamination of soil and groundwater according to a survey by Rester (1987). Taylor et al (1987) discussed rinsewater recycling but concluded that the practicality of the process diminishes as the variety of crops grown increases. The larger number of pesticides used makes incompatibility of pesticides or adverse effects more likely. Pesticide waste may also be treated by the use of carbon adsorption plants. Nye and Way (1987) and Johnson and Harris (1989) describe the use of flocculation tanks and carbon filtration and concluded that the treatment process was effective in removing pesticide from waste waters.

Some years ago, shallow evaporation pits were used in the hot climate of California to evaporate pesticide and waste water, but these have recently been made illegal as a number were found to be leaking into the soil. Researchers are developing biological treatments for waste water; Craigmill et al (1987), for example, investigated the use of farm manure, lime and blood meal to break down pesticide wastes.

The USDA recently launched a research plan costing $8-10 million to improve water quality, (USDA, 1989), (see Appendix D). The intention is to document sources and amounts of hazardous contaminants in groundwater attributable to agriculture and forestry, and develop and evaluate ways of reducing the problem.

2.1.4 <u>Legislation</u>

Current UK and EC legislation has prompted significant moves towards safer practices for the storage, handling, application and disposal of pesticides. The development of the 'single market and common laws' within the Community, in

January 1993, will result in further legislation. The Code of Practice, MAFF/HSC (1990) gives farmers and growers guidance on meeting their responsibilities under Part III of the Food and Environment Protection Act, 1985 (FEPA) and in particular the Control of Pesticides Regulations 1986 (COPR) and the Control of Substances Hazardous to Health Act (COSHH). COSHH, enacted in October 1989, requires the exposure to hazardous substances hazardous to health to be either prevented or, where this is not reasonably practicable, adequately controlled. Regulation 7 (2) requires that prevention or control is secured by measures other than the provision of personal protective equipment. Control must, so far as is reasonably practicable, be by engineering control methods. The parallel development of injection sprayers and closed transfer systems meets with the approval of legislators as engineering controls. The use of returnable containers will further protect the operator from the hazards associated with pesticide use.

Under part one of the Control of Pollution Act (1974) it is an offence to abandon or dispose of waste which is poisonous, noxious or polluting on any land where it is likely to give rise to an environmental hazard. Under the Water Act (1989) it is an offence to cause or knowingly permit any poisonous, noxious or polluting matter to enter controlled waters. The elimination of tank washing and subsequent rinsate disposal with direct injection sprayers overcomes the operator and environmental problems at source, (Landers, 1990).

The Governments of Sweden and Norway aim to reduce pesticides by 50% states Nordby (1989); the Swedish Government levies a tax on each pesticide treatment. In Denmark the Government aimed at a reduction of 25% of active ingredients in pesticides by 1990 and a further 25% cut before 1997, (Thonke, 1988). In Holland there is a similar move to reduce pesticide use by 50%. In Holland, under the STORL covenant, (Stichting Opruiming Restanten Landbouwbestrijdingsmiddelen) a maximum acceptable residue level of 0.01% of the original pesticide has been agreed as acceptable for a container rinsing standard. Returnable containers would overcome this requirement and the problem of container disposal.

California has become the model for many Federal and State laws governing pesticide use. In 1973 California required the use of closed transfer systems for category one toxic pesticides. Good sprayer waste management is being encouraged by training and legislation. Appendix D contains the report 'The effect of legislation on the application of pesticides in the State of California', (Landers, 1989c).

Figure 2.2 <u>**The basic concept of a direct injection sprayer**</u>

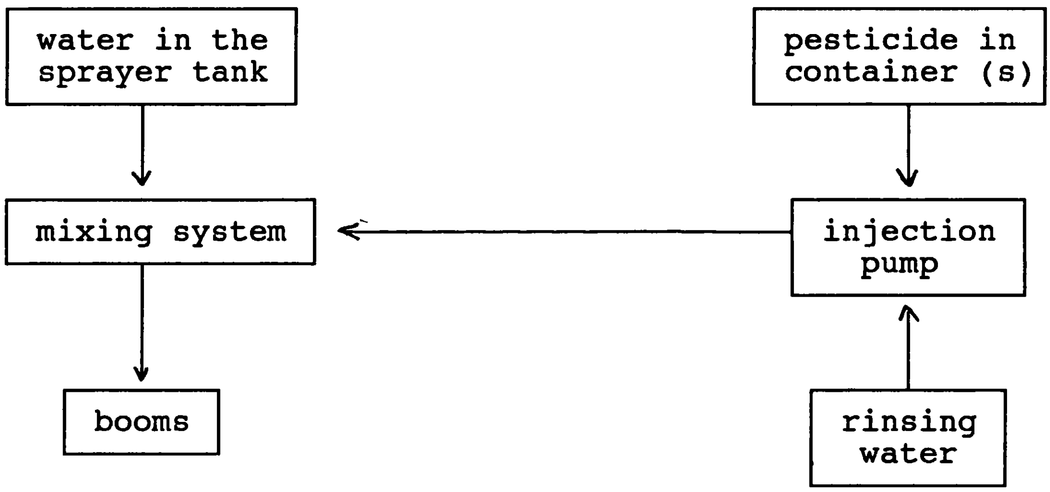


Figure 2.3 INJECTION SPRAYER

Injecting pesticide

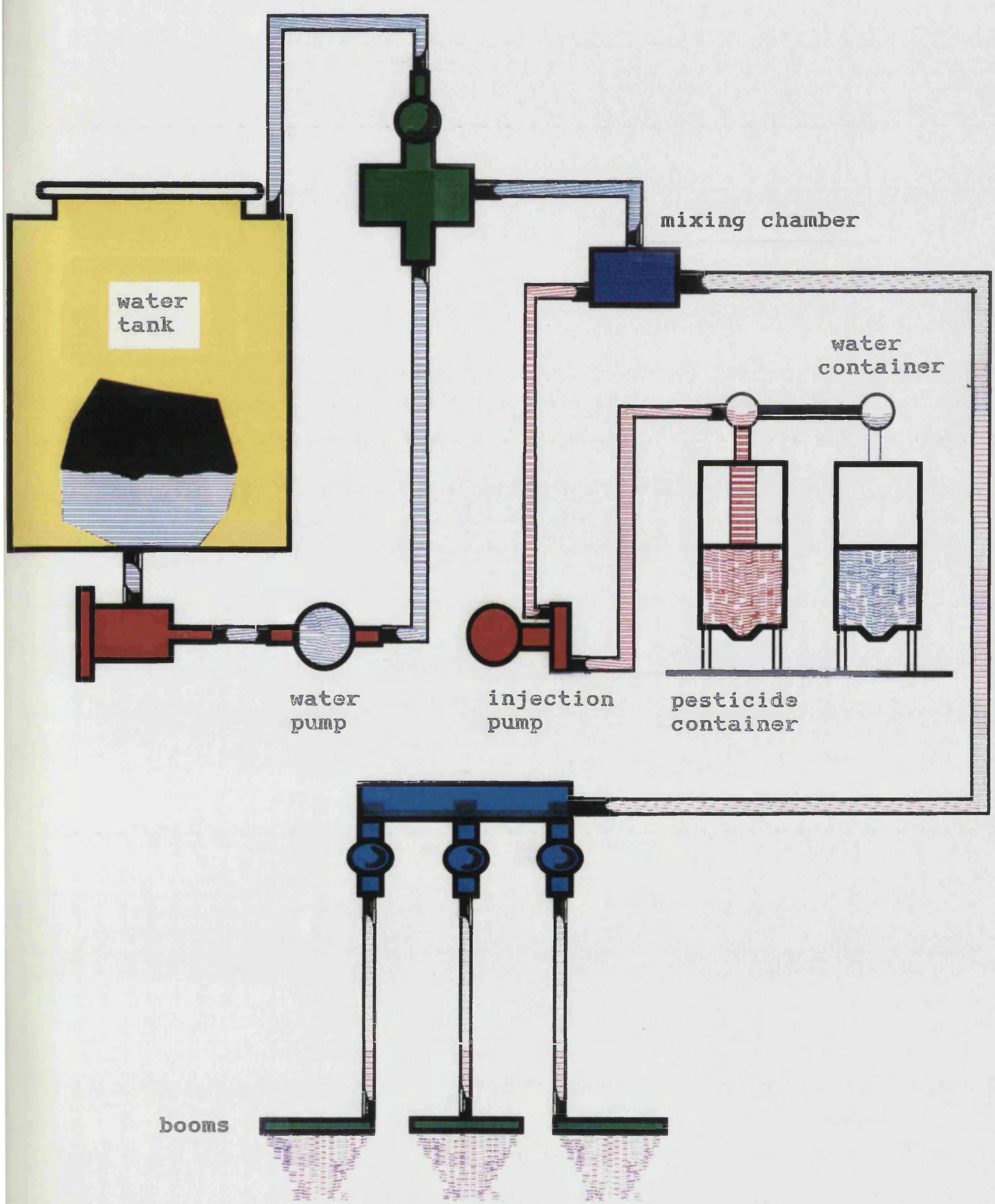


Figure 2.4 INJECTION SPRAYER

Injecting rinsewater

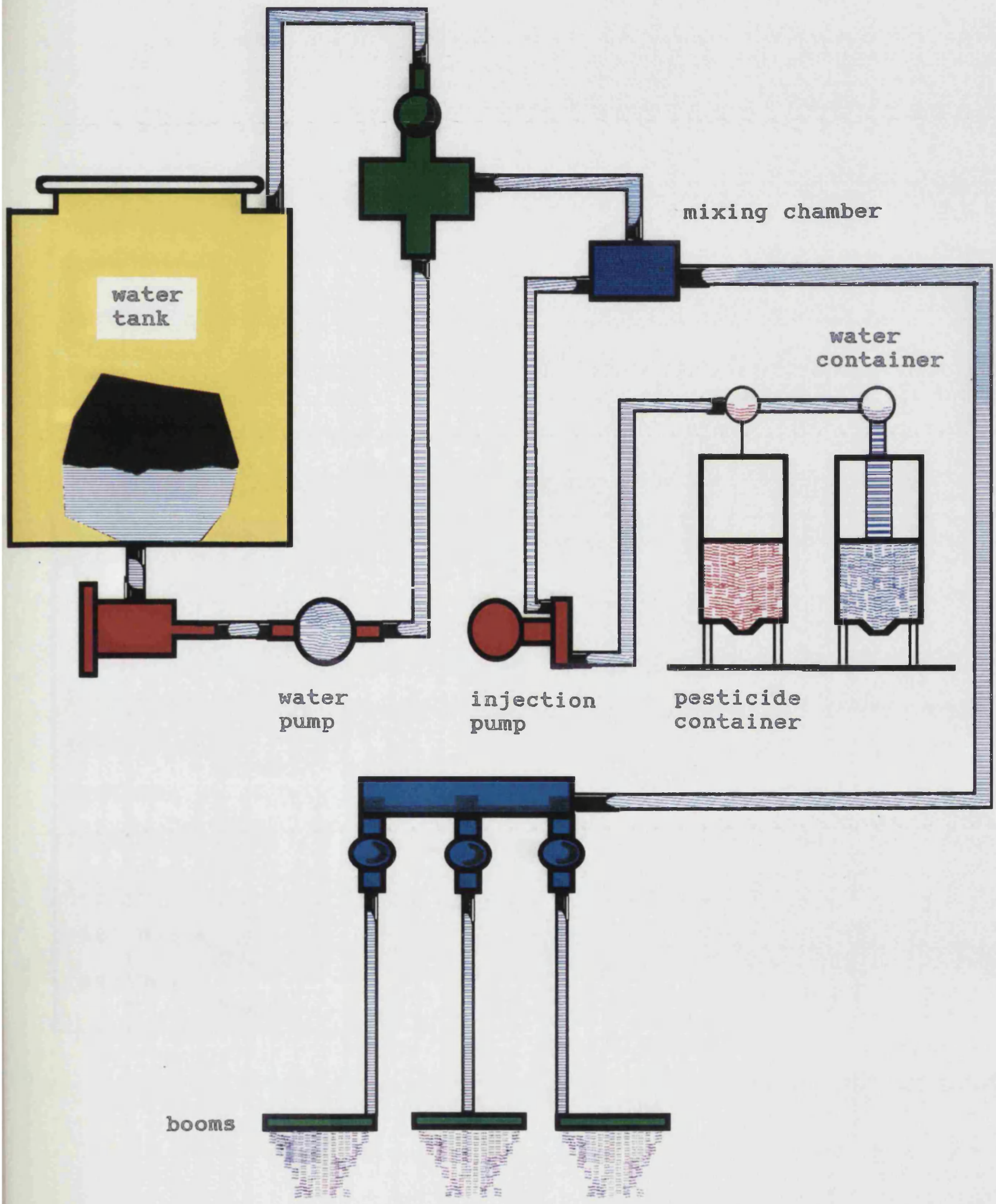


Table 2.1 <u>Chronological development of injection sprayers</u>

YEAR	NAME AND COUNTRY	INJECTION METHOD Gra-vity	INJECTION METHOD Mech. pump	INJECTION METHOD Pneu-matic	INJECTION POSITION suction side	INJECTION POSITION pressure side	APPENDIX No.
1970	Amsden U.K		*		*	*	A.1
1973	Harrell et al USA		powder		*		A.2
1975	Vidrine et al USA		*			*	A.3
1975	Peck & Roth USA		* & powder			*	A.4
1976	Hoenderken Holland			*		*	A.5
1976	Tennes et al USA		*			*	A.6
1982	Eho Finland		*			*	A.7
1982	Schmidt Germany			*		*	A.8
1982	Larson USA		*			*	A.9
1983	Reichard& Ladd USA		*			*	A.10
1984	Gebhardt et al USA	*				*	A.11
1984	Humphries&West Australia		*			*	A.12
1984	Ostarhild Germany		*			*	A.13
1985	Lindner Germany		*			*	A.13
1985	Cho et al USA		*			*	A.14
1986	Grunewald USA		*		*		A.15
1986	Pami Canada		*		*		A.16
1987	Koo et al USA			*		*	A.17
1987	Pami Canada		*			*	A.18

Table 2.1 __Chronological development of injection sprayers continued__

YEAR	NAME AND COUNTRY	INJECTION METHOD: Gra-vity	INJECTION METHOD: Mech. pump	INJECTION METHOD: Pneu-matic	INJECTION POSITION: suction side	INJECTION POSITION: pressure side	APPENDIX No.
1988	Crook Australia					*	A.19
1988	Beijaard Holland		*		*		A.20
1988	Budwig et al USA		*			*	A.21
1988	Chi et al Canada		*			*	A.22
1988	Frost U.K		*			*	A.23
1988	Wallenas Sweden		*			*	A.24
1988	Tompkins et al USA		*		*	*	A.25
1989	David Germany		*			*	A.26
1989	Doser France		*			*	A.27
1989	Hart& Gaultney USA		powder		*		A.28
1989	Lindus Sweden		*			*	A.29
1989	Way et al USA		*			*	A.30
1990	Ghate& Phatak USA			*		*	A.31
1990	Spugnoli & Vieri, Italy		*			*	A.32
1991	Schonlebers Germany			*		*	A.33

2.2 THE PRINCIPLE OF DIRECT INJECTION SPRAYERS

An injection system comprising one to four pumps which will dispense pesticide at a known rate into the water stream in the sprayer pipeline can be added to a conventional crop sprayer in such a way that the main tank of the sprayer holds clean water only. The pesticide is mixed with the water, either in a manifold or at the main water pump, and the resultant mixture of pesticide and water then flows to the booms (see Figure 2.2, 2.3 and 2.4).

On more advanced designs an electronic controller adjusts the pesticide pump output according to changes in operating parameters, e.g. boom sections switched on/off, changes in forward speed, or the need to modify the dose per unit area.

Methods of injecting concentrated pesticide formulations directly into the sprayer pipeline, have been documented since Amsden (1970) first described various methods of pesticide injection. With direct injection systems pre-mixing of pesticide and water is no longer required since the sprayer tank now contains only clean water. The technique helps the operator work more safely because it reduces the contamination associated with mixing and pouring pesticides into sprayers, as described by Abbot et al (1987), section 2.1.1.

Pesticide injection also ensures accurate and safe metering of the concentrated product. This has considerable financial benefits in both saving operator time and reduced product wastage. The elimination of tank washing reduces the risk of environmental pollution, see section 2.1.3 above, but the metering pump, the hoses and nozzles will still require washing.

The chronological development of injection sprayers can be seen in Table 2.1, and Appendices A1 - A33 contain a diagram and description of each system. Injection sprayers have been designed and developed in many countries. The majority of these use some form of mechanical pump to inject pesticide into the pressure line after the main water pump. The alternative low pressure pumps, e.g. peristaltic pumps, meter pesticide into the suction side of the water pump to overcome the pressure problems and to obtain good mixing of pesticide and water in the main pump.

The materials from which injection sprayers are made are subject to attack from the pesticides being used, and for example, organic solvents attack plastics and rubber. Amsden and Southcombe (1977) discussed the problems associated with chemical and physico-chemical attack and noted that the severity of attack falls as the pesticide is diluted but over a period of time the cumulative effect can still be devastating. They concluded that by understanding the nature of such attack means can be found to minimise the problem.

One way of reducing some of the problems associated with pumping pesticides, such as high viscosity and chemical attack, is to use a pressure source to inject the pesticide. The use of pneumatic pressure for an injection sprayer was developed by IMAG in Holland, (Hoenderken, 1976), originally using propane gas which was potentially dangerous and could contaminate the pesticide, IMAG subsequently developed the use of compressed air to apply phenmedipham (Betanal) to sugar beet, compressed air being available on some tractors and safer than propane. The use of compressed air to inject pesticides into a field sprayer was developed by Schmidt (1982). Pesticide was contained in a replaceable pesticide tank and flow was adjusted according to the pressure difference between the water line and the pesticide tank. Laboratory tests showed a linear relationship between pressure difference and pesticide flow. Ghate and Phatak (1990) developed a similar technique of pressurising the pesticide tank, but also used compressed air to pressurise the water tank. Water flow was dependent on tank pressure and nozzle hole size and pesticide flow by air pressure and the needle valve of a flow meter. A German farmer, Herr Schonlebers, developed a device which uses the compressor on the tractor to pressurise a stainless steel pesticide container, (Preusse, 1991). The farm-built system can inject one to three products.

Landers (1989b) described the recent development of injection sprayers in Europe. Two systems are commercially available, the Swedish AgriFutura Dose 2000, (Wallenas, 1988), and the Mid-West Technology (Walsh) CCI 2000, from America, developed by Grunewald (1986).

Other systems are under development including one by the Dutch sprayer manufacturer, Vicon, whose injection sprayer uses a novel peristaltic pump, (Beijaard, 1988). In this system the dual pipe peristaltic pump allows a wide variation in application rates due to the use of a combination of small and large bore pipes'. Silsoe Research Institute has developed an interesting injection system comprising a piston and cylinder device to extract pesticide from the original container. The injection pump pumps only water, thus overcoming pump problems associated with pesticide viscosities and is being evaluated by Frost (1988).

Simple water driven pumps are currently undergoing trials in Germany (David, 1989), France, (Doser, 1989) and in Italy (Spugnoli and Vieri, 1990). The German pump which is being developed in conjunction with pesticide manufacturer Ciba-Geigy has a single water pump which can have up to four pesticide pumps attached to it. The French sprayer manufacturer, Tecnoma, is investigating the use of the Dosatron injector/dilutor, (Doser, 1989). A similar dilutor is being developed at the University of Firenza, Italy (Spugnoli and Vieri, 1990)

2.3 LABORATORY TESTS ON THE INJECTION PUMP DESIGN AND CONTROL

Schmidt (1983) states that in extreme situations, dependent on boom width, speed and active substance application rate, the metered flow may require values of between 4 ml/min and 3600 ml/min. The pump must be accurate throughout the range of outputs required.

Hughes (1982) proposed a micro-processor based control system which could reduce the effect of errors such as incorrect calibration of the metering pump. Hughes and Frost (1985) concluded that the accuracy of a control system depends on the accuracy of the signal it receives, and therefore the transducers for measuring flow rates and forward speed must be accurate and reliable.

Two pumps, the simple piston pump made by EHO in Finland and the Pulsa Feeder diaphragm piston pump from America, were evaluated by Cho et al (1985). The simple piston pump flow rates did not change in a linear fashion with the length of stroke setting, resulting in smaller than expected flow rates. The reason for these errors were:-

a) decreased flow due to back pressure when injecting into the sprayer system,

b) worn piston seals,

c) small-bore pipe restricting pesticide flow into the pump.

Obviously, such inaccuracies in pump output are unacceptable, which prompted Chi et al (1988a and 1988b) to devise a flow control system using electro-mechanical feedback to control the pump speed, and keep the pressure drop to zero. Test results showed the system worked well with fluids of varying viscosities and different flow rates.

Way et al (1989) assessed the accuracy of two peristaltic pumps, the Masterflex 7018-40 and the Randolph 610, with three pesticides at two temperatures and pressures. Their results showed that if a pump is calibrated for only one herbicide, temperature and pressure, the resulting error could be quite large under other conditions and they recorded errors of 39% for the Masterflex pump and 111% for the Randolph pump. They suggested that the peristaltic pumps should be calibrated for each pesticide used at a given temperature and pressure.

2.4 LABORATORY TESTS USING LIQUIDS

Four different nozzle designs were tested by Larson et al (1982) to evaluate pesticide injection at the sprayer nozzle. A laboratory unit was developed in which red fluorescent dye could be injected into the nozzles and a Spectronic 20 colorimeter was used to measure how the mixing varied across the spray pattern. A plugged nozzle, with holes on the side and no swirl plate, gave the lowest standard deviation and was field tested using Malathion.

Flow rate, density and viscosity using a closed-loop control system employing a flow meter sensor was measured by Gebhardt et al (1984). Viscosity tests were carried out on five pesticides at a range of temperatures that could be encountered under field conditions in North America. Temperatures of 15.6, 26.7 and 37.8 ^{o}C were chosen for flow meter tests as being representative of the ambient air temperature during which the majority of pesticides are applied. They noted the change in density was small when pesticides were subjected to a 22 ^{o}C temperature change. The viscosity characteristics of certain pesticides were Newtonian (the viscosity remained constant for all shear rates) whereas other pesticides demonstrated non-Newtonian properties.

The uniformity of pesticide concentrations after injection, metering pump characteristics and field performance was investigated by Cho et al (1985). Two types of injection pump, the EHO piston pump and the Pulsa feeder Interpace Corp. 680-diaphragm pump were tested. Concentration levels were obtained using two methods. In the first, common salt (NaCl) concentrations were estimated by drying the sample and weighing the residual salt, while in the second methylene blue was estimated by the light absorbency of samples using a spectrophotometer.

When a pesticide is injected into a spray boom there is a time delay before the change in concentration is fully established at the nozzle. Koo et al (1987) assessed the physical significance of these time delays by writing a simulation model, which was validated by using the fluorescent dye Rhodamine B with a fluorometer at the nozzle. Changes in concentration levels were recorded on a data acquisition system.

Chi et al (1988a) and (1988b) developed a flow rate control system to measure and control low volume pesticide flow rates from an injection pump. Tests were conducted using two types of oil with different viscosities. The oil was collected in a measuring cylinder.

Operational performances were evaluated by Tompkins et al (1988) using three different pumps, a peristaltic roller pump and two piston pumps, and injecting pesticide at three different locations on the sprayer, upstream and downstream of the main pump and at individual nozzles. Potassium bromide was used to mimic the pesticide and concentration levels were detected using a field conductivity meter.

Pesticide mixing effectiveness and response times were monitored by Budwig at al (1988) using potassium permanganate ($KMnO_4$) as the dye, with an optical detection system based upon an Aerotech LSR5P He-Ne laser unit fitted to the sprayer boom. A laser beam passed through a glass sampling cell and the light not absorbed by the solution was picked up on a photo-detector.

Ghate and Phatak (1990) used a colorimeter to analyse solutions of glyphosate and methomyl and chemical analysis to assess samples of glyphosate and alachlor, to see if the mixing of pesticide and water was uniform. Tests with paraquat and glyphosate were carried out in the field to test the consistency of solutions in the crop sprayer.

The volume of pipe between the injection point and the nozzles is critical in determining the time lag before the pesticide reaches the nozzle.

2.5 LABORATORY TESTS USING POWDERS

The need to mix insoluble dry pesticides with water to make suspensions that can be sprayed, led Harrell et al (1973) to develop further a novel powder dispensing unit, which had been described by Hare et al (1969). Talcum powder was dispensed into a mixing vessel on a conventional sprayer. Samples were taken in the laboratory at two minute intervals, poured through pre-weighed filter paper in glass funnels, placed in an oven and dried. The results indicated that an experimental sprayer fitted with a centrifugal pump could be used to give satisfactory results.

More recently, Hart and Gaultney (1989) developed a direct injection system for dry flowable pesticides using a metering/crushing screw to reduce packaged formulation particle sizes into suitable form for dispensing into the water flow in a crop sprayer. The metering/crushing unit was evaluated using ten proprietary brands of pesticide. The unit was found to meter certain pesticides extremely well in a laboratory test sprayer.

2.6 FIELD TESTS

Vidrine et al (1975) considered that the two operating conditions most likely to cause severe application rate errors with injection sprayers were:-

a) when the sprayer first enters the field with the boom lines completely void of pesticide and

b) when changing speed.

Errors occurring at (a) could be avoided by starting the sprayer prior to reaching the field rows to ensure that pesticide concentration in the spray lines is consistent with row entry speed. The time delay depends on the flow rate and the pipeline volume.

A crop sprayer featuring ground-driven liquid and powder metering units and a jet pump to induce pesticide into the boom suppply line was developed by Peck and Roth (1975).The pesticide/water mixture leaving the jet pump entered a distribution system with four feeder lines. Each of the feeder lines was of equal length and led to the centre nozzle of a three nozzle assembly on the boom. The lines were selected to minimise the storage volume whilst

providing sufficient velocity to prevent particles settling out.
Reichard and Ladd (1983) carried out field tests with Carbaryl 80W to control Colorado Beetle (*Leptinotarsa decimlineate*) in a potato crop. They noted that pesticide delay times depend on the volume contained in the plumbing between the point of injection and the nozzle and the flow rate of the liquid in the lines.

The Australian Terramatic boom sprayer applies pesticide at variable ground speeds. By adjusting the pesticide concentration in the water stream an inevitable time lag occurs when ground speed is altered. Humphries and West (1984) minimised the delay by using narrow bore piping (9.5mm) to supply the boom line. The pesticide/water mixture is also injected at three spaced points to ensure even distribution. They claimed a time of 4.2 seconds or 21 metres when applying 50 litres per ha through an 18 metre boom when changing forward speed from 12 to 18 km/h.

PAMI (1986) tested the Canadian Ag-Chemical Injection Model 240 and experienced time delays ranging from 1.2 to 4.7 minutes for the pesticide to reach the last nozzle. A 27.4 metre boom operating at 40 litres per ha had a delay of 3 minutes. An 18.3 metre boom operating at 40 litres per ha had a delay of 4.7 minutes which was reduced to 1.6 minutes when operating at 110 litres per ha. He concluded that the response time was excessive and would not allow uniform application of pesticide.

The physical significance of time delays and their impact on typical spraying situations was assessed by Koo et al (1987). They concluded that anything which can be done to increase the velocity in the boom will, in turn, reduce delay times. An example quoted from their simulation model showed that a reduction in boom diameter from 19mm to 13mm resulted in a reduction in the area which had mis-application errors greater than 10% from 6.7ha to 5.2 ha in a 16.2 ha field.

PAMI (1987) tested the Australian-Canadian Computorspray (SSCIMS). Time delays for the pesticide to reach the last nozzle were acceptable on a 24 metre boom at 100 litres per ha but were unacceptable at the lower rates of:

50 litres per ha resulting in a 44.5 metre delay
30 litres per ha resulting in a 80.0 metre delay.

A study at Silsoe Research Institute has shown that the time delay need be no more than three or four seconds for a 24 metre sprayer if the system is well designed. Legg and Miller (1989) suggest that if shorter lag times are needed, it will be necessary to use multiple injector points or small bore piping and more expensive pumps. The use of small bore pipes will result in increased friction affecting the flow of pesticide.

2.7 OTHER USES OF INJECTORS AND DILUTORS ON FARMS

The mixing of chemicals with water is required in many different aspects of animal and crop husbandry. For many years farmers and growers have used injection or dilution techniques. The automatic administration of drugs, feed and vitamin supplements for livestock production uses a dilutor fitted into the water supply line to the water troughs. Fertilizers and pesticides can be injected into the irrigation lines of greenhouses, and computers are often used to control and adjust the rate automatically. Such injection of fertilizers and pesticides into field irrigation pipelines is referred to as 'fertigation or chemigation'. Threadgill (1985) and Eisenhauer and Bockstadter (1990) have conducted trials to assess the accuracy of injection pumps in metering products in 'chemigation', and the metering appears to be accurate enough to make 'chemigation' via the leaves and roots workable. Metering pumps are also used in a number of situations for the introduction of sterilizing and disinfecting products. For example, many dilutors are used on dairy farms to sterilize the milk pipelines after use. A dilution pump can also be used to ensure that the correct strength of insecticide is maintained in a sheep dipping bath and the Cooper 'Powerpack' has been developed to maintain the insecticide concentration when the water level is topped up in the dipping bath.

Fungicides can be applied to potatoes by using a peristaltic pump to inject pesticide onto a spinning disc before an electrostatic charge is applied to the droplets. The charged fungicide is used to treat potatoes on their way into storage.

Tennes et al (1976) in a paper on the concept of an enclosed canopy sprayer for applying pesticides to fruit trees described a sprayer which incorporated four injection pumps to allow one or more pesticides to be used simultaneously. The canopy sprayer should also reduce drift, which is emerging as a major problem with orchard blast sprayers.

CHAPTER 3. MATERIALS AND METHODOLOGY

The increasing awareness of the limitations of conventional crop sprayers mentioned in Chapter 2 has resulted in the development of direct injection crop sprayers which have the potential to eliminate some of those problems.

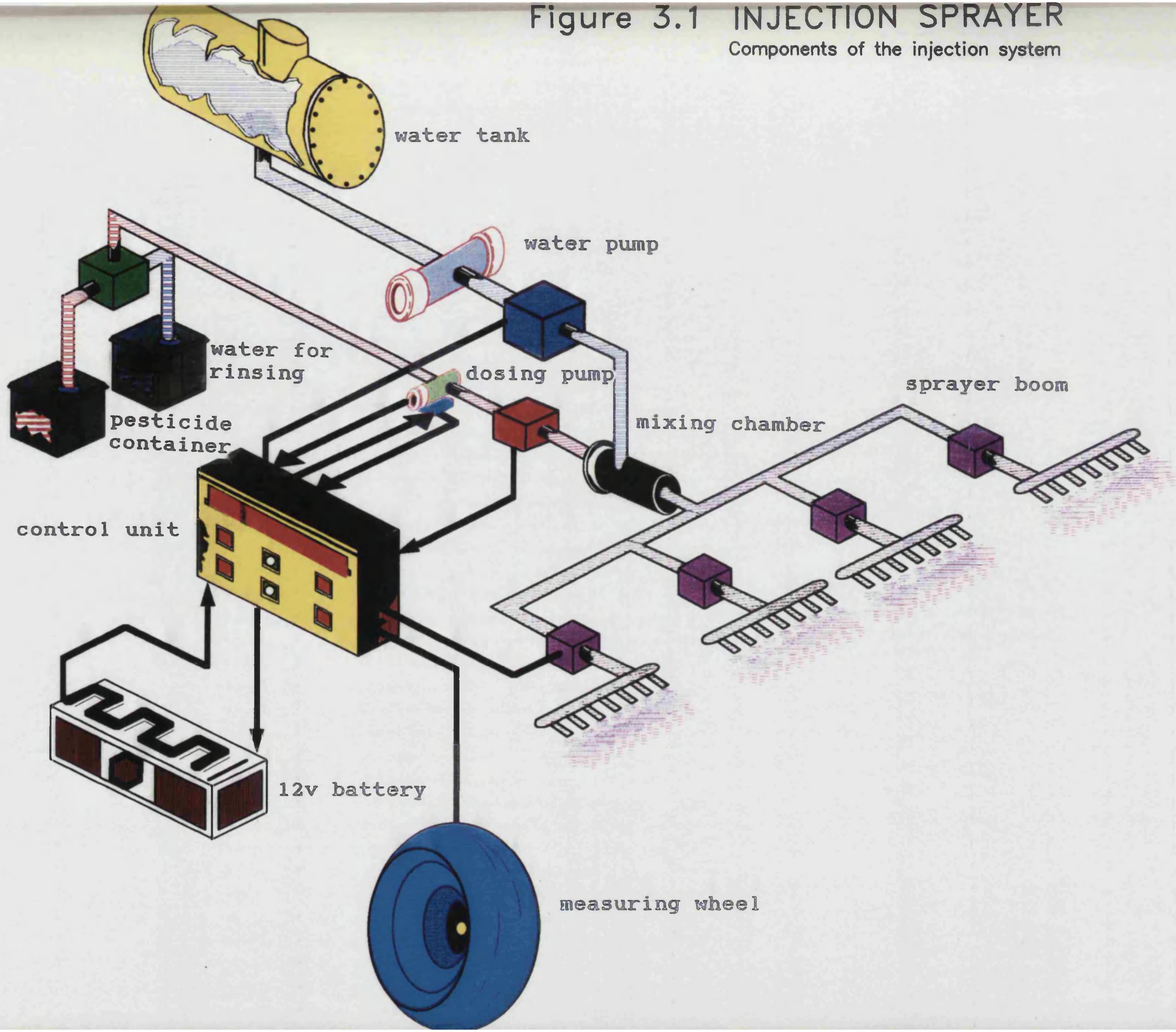
The overall objective of the research undertaken was to evaluate the accuracy and operational performance of components suitable for metering and mixing pesticides and the results of these trials form the basis of this thesis.

3.1 DESCRIPTION OF THE COMPONENTS OF AN INJECTION SYSTEM

Figure 3.1 shows the components of an injection system and Appendix B details their design and construction. Plates 3.1 and 3.2 show the prototype injection system fitted to a Hardi TZ 1500 sprayer for trial work at the Royal Agricultural College. Plates 3.3 and 3.4 show the injection unit fitted to a Chafer T2000 sprayer for large-scale field trials at Weasenham Farms.

Figure 3.1 INJECTION SPRAYER

Components of the injection system



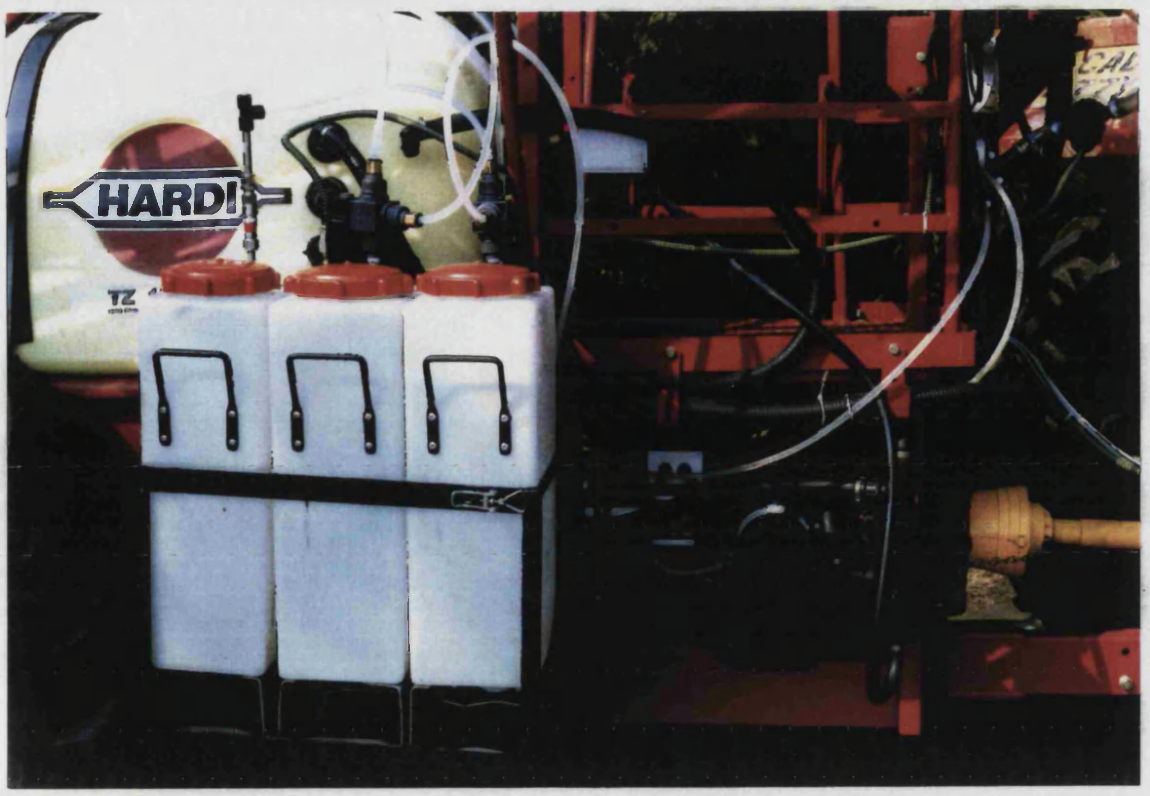


Plate 3.1
Prototype injection system using two pumps fitted to a Hardi 20m sprayer for field trials at the Royal Agricultural College

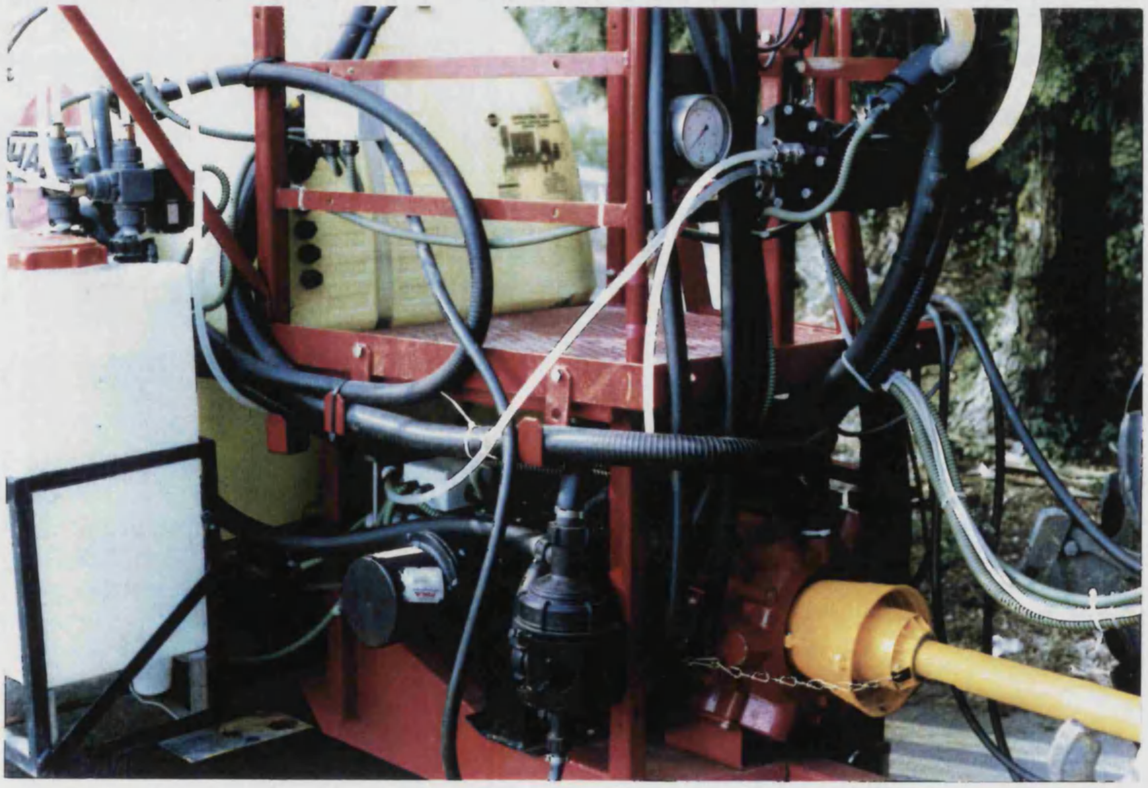


Plate 3.2
Prototype injection system illustrating the pumps, mixing chamber and pto drive

Plate 3.3
Injection system fitted to a Chafer T2000 sprayer for large-scale field trials at the Weasenham Farming Company

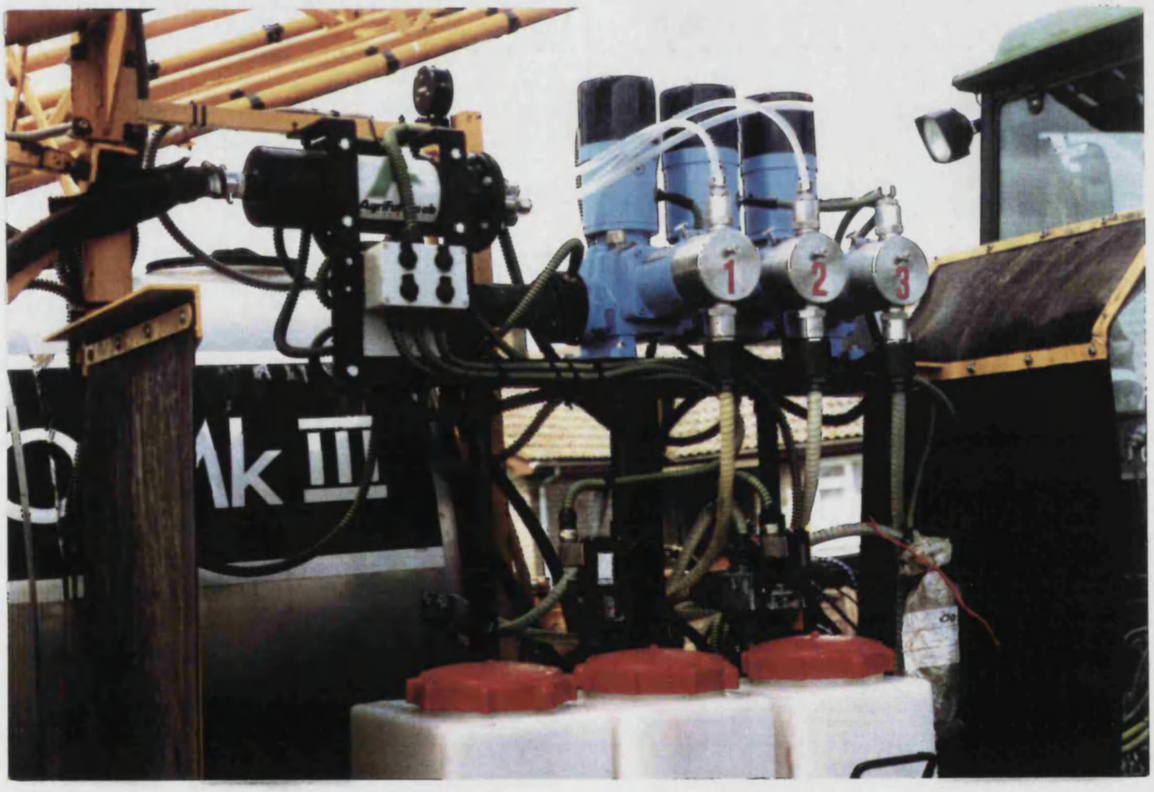


Plate 3.4
A close-up of three injection pumps driven by an hydraulic motor, the mixing chamber, two pesticide containers and one rinsewater container

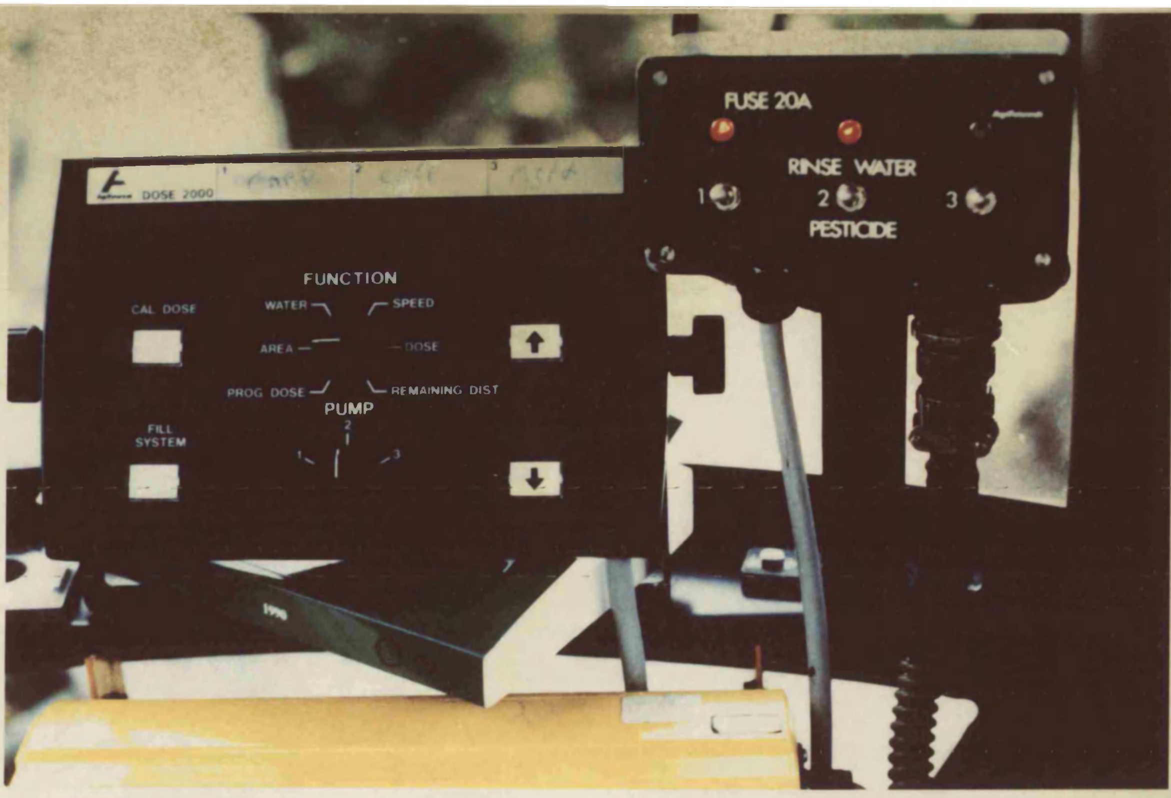


Plate 3.5
The in-cab electronic controller and remote control unit

Plate 3.6
Measuring pesticide viscosity using a DIN No.4 beaker

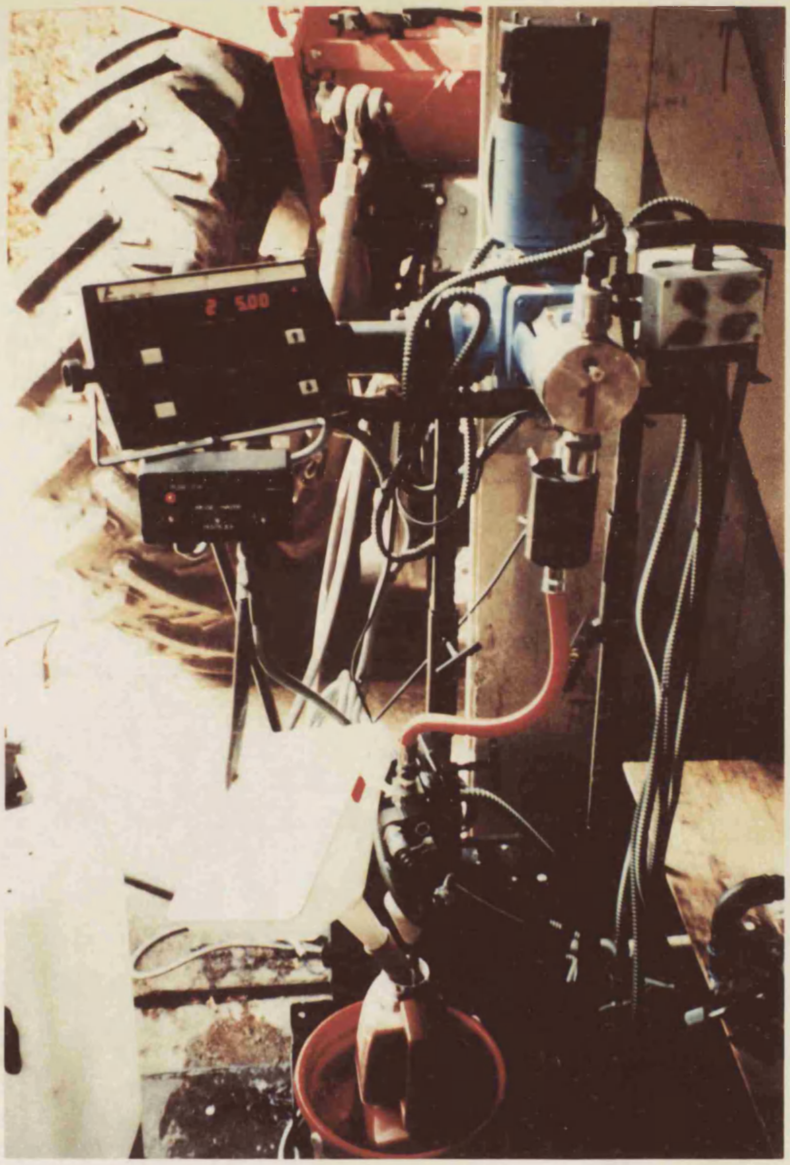


Plate 3.7
The single pump test unit being used to determine the effect of formulation and temperature on the metering accuracy of the injection pump. The pesticide container is in a heated water bath

The direct injection system is designed to inject pesticide into a crop sprayer during spraying. The system consists of three main components:

a) pesticide containers,

b) pumps and monitoring unit,

c) mixing chamber.

The pesticide containers need to match the sprayer water tank capacity so that they may be refilled at the same time e.g a sprayer with a 2000 litre water tank operating at 200 l/ha will cover 10 ha per fill; injecting pesticide at 2.5 l/ha will require 25 litre containers. The weight of the filled containers must also be such that they can be handled without difficulty. In operation the pesticide containers mounted on the machine are filled, from the pesticide manufacturer's original containers using a filling station comprising a probe and an electric pump. Pesticide is withdrawn from the mounted container by means of a probe connected via a pipe to the injection pump; to ensure the containers empty completely, the probe reaches down into a well formed in the base of the container.

The injection point can be situated before or after the main water pump, the advantage of placing it after the water pump being that because the water pump is not contaminated with pesticides the pump diaphragm has a longer life and there is less risk of operator contamination during water pump maintenance. The disadvantage is that a high pressure injection pump needs to be considered capable of injecting pesticide at or above normal crop spraying pressures of 0.5-4 bar. Furthermore, injecting pesticide after the main pump means that pesticide has to be pumped through a pipe at a pressure in excess of 4 bar.

The injection pump needs to be able to inject accurately pesticides with varying viscosities and formulated in a variety of ways such as water soluble products, dispersable granules, wettable powders or emulsifiable concentrates.

The injection pump needs to be very durable to withstand the aggressive action of pesticides and their solvents and to accomplish this a pump with a ceramic piston in a stainless steel cylinder and PTFE seals was chosen. The output of the pump needs to be adjustable to take into consideration changes in operating parameters such as:

a) forward speed

b) a wide range of possible dose levels and

c) the number of boom sections open

A stepper motor was chosen by the manufacturers of the injection pump used in this work to allow an electronic controller to adjust the piston pump stroke length automatically.

The mixing chamber needs to mix the pesticide and water thoroughly to avoid scorching the crop or under-applying pesticide, both of which could result in crop loss. The chamber needs to be large enough to even out the pulsating effect of the piston pump yet small enough so as not to create a long time delay when changing dose levels. The

mixing of the pesticide with water takes place continuously in the mixing chamber which needs to be situated as close as possible to the rear of the sprayer to reduce time delays. A simple 2 litre cylindrical mixing chamber was designed to ensure effective mixing of pesticide and water (Wallenas 1988). Water enters at the side of the chamber, the pesticide enters at one end and the mixture leaves the chamber at the opposite end.
A detailed description of the injection pump, stepper motor and in-cab control box can be found in Appendix B.

The crop sprayers used in the tests were:

i) Hardi TX1500 trailed sprayer with 20m booms, fitted with a diaphragm pump and electric boom valves. The sprayer was used with Hardi turret nozzles fitted with:

   a) Blue, F110/1.11/3 nozzles,

   b) Red, F110/1.59/3 nozzles.

An electronic speed simulator was fitted to give a forward speed of 8.7km/h, and at 1.5 bar pressure an output of 100 l/ha was achieved with the blue nozzles. At 8.7km/h and 2.5 bar pressure an output of 200 l/ha was achieved with the red nozzles.

ii) A Chafer T20000 trailed sprayer fitted with a 24m boom. This sprayer was used for the large-scale field trial at Weasenham Farms.

3.2 LABORATORY TRIALS TO ASSESS PUMP ACCURACY

Objectives were:

1. To study the accuracy of the injection pump at various dose levels.
2. To observe the linearity of the pump output.
3. To find the 'True Step 0' for pump synchronisation.
4. To observe the accuracy of the pump drive mechanism.

3.2.1 Observations on the linearity of pump output

A 30 litre pesticide container was filled with water to a preset level. The depth of water was monitored by a sensitive float switch connected to a 12v battery and light bulb. As the injection pump under test extracted the water, the level dropped in the container. The water level was returned to the preset depth by filling with water until the float switch completed the circuit between the battery and the bulb. An Avery electronic weighing scale was used to weigh the amount of water necessary to return the water level to its original depth.

The pump and pipelines were primed for a few minutes to ensure that there were no air bubbles in the system. Measurements were taken every 200 steps from step number 200 to step number 2000. The in-cab electronic controller was set to manual operation and each step number was digitally displayed. At the shorter stroke lengths (low dose rates) the pump was run for as long as possible eg 30 minutes, resulting in a more accurate reading due to the greater quantity dispensed from the pump.

3.3 BOOM FLOW CHARACTERISTICS

Objectives were to observe:

1. The uniformity of pesticide concentration from nozzle to nozzle.
2. The uniformity of pesticide concentration as a function of time with changes in forward speed and dose level.
3. The system response time during changes in forward speed and dose levels.
4. The use of a purge mode to rinse the sprayer pipes.
5. The injection pump characteristics.

Potassium permanganate ($KMnO_4$) was used as an indicator to be injected into the water. This dye was chosen as it is relatively inexpensive, readily available, moderately safe to work with and does not leave objectionable stains. The stock solution was 0.5g of potassium permanganate per litre of water.

A CECIL CE 2393 Digital Grating Spectrophotometer operating at 500nm wavelength was used to analyse the samples. The apparatus has a Tungsten Halide lamp and operates from 280nm to 980nm. The CECIL gives a digital display of results in Absorbence, Concentration and Transmittance. The apparatus was set using three standards:

0000:	distilled water
0.250:	0.025mg/ml of $KMnO_4$
0.500	0.050mg/ml of $KMnO_4$

37ml containers were placed under each nozzle for three seconds at five or ten second intervals, depending on the test requirement. In all the tests three replications were used.

3.4 SYSTEM PURGE TRIALS

Any pesticide residues in the injection system would lead to the carry over of injurious products to another crop, resulting in crop damage. The remote control switch, Appendix B, allows the operator to switch from pesticide to flushing water, thus purging the system of pesticide.

Objectives were:

1. To calculate the quantity of rinse water required to flush pesticide from the pipe at the container valve, through the injection pump head to the injector situated in the mixing chamber.
2. To evaluate the effectiveness of a proprietary flushing solution and compare it with water.

An injection pump, driven by an hydraulic motor (as described in section 3.5), was connected to a container of Isoproturon (Hytane 500 FW, Ciba-Geigy 500g/l) and a container of flushing solution. The pipe volume from the container valve to the injector was 146 ml. The in-cab controller set at 2.5 l/ha. After pumping Isoproturon for five minutes, the container valve was switched to the rinsing mode and the pump discharge (wash solution) collected in a row of 500ml beakers. Each wash solution sample was prepared using a technique recommended by Lees (1991) and detailed in Figure C.1, Appendix C. The samples were analysed using a Thin Layer Chromatography technique described by Browning (1989); TLC plates were spotted with prepared samples and a standard reference solution and held under an ultra-violet lamp.

Two tests were carried out:

a) using water as the flushing solution
b) using 'Supray Spraynett', a proprietary sprayer tank cleaner at the recommended rate of 0.25litre/25litres of water.

'Supray Spraynett', from Tecnoma of France was chosen as it can be sprayed onto crops without damaging them; it is based on an organic solvent and wetting agent.

3.5 METERING LIQUID PESTICIDES OF VARYING VISCOSITIES AT DIFFERENT TEMPERATURES

Objectives were:

1. To determine the effect of pesticide formulation and temperature on the metering accuracy of the injection pump.
2. To determine the importance of calibrating the injection pump when operating conditions differ from the original calibration conditions.
3. To observe the repeatability of pump output at a given dose level.

The injection pump was mounted on a steel frame. The pump was driven by a Danfoss OMM 20 hydraulic motor connected to a tractor giving an oil flow of 20 l/m. The suction side of the pump was connected, via an insulated pipe, to a six litre pesticide container immersed in a water bath, Plate 3.7. The pump outlet was connected, via a dry-break connector, to an injector mounted on the lid of a pressure vessel. The pressure vessel was connected to an air compressor and the pressure regulated to 3 bar; a pressure gauge indicated operating pressure.

Inside the pressure vessel a six litre container collected the pesticide. An electronic scale was used to weigh the collected pesticide and a one litre measuring cylinder was used to calibrate the pesticide density.

The viscosity of the pesticide was measured using a Din No 4 beaker (100ml running out through a 4mm hole). The beaker was used for the comparative testing of pesticide viscosities, Plate 3.6.

The pesticide was pumped at three temperatures, $8^{o}16^{o}$and $32^{o}C$. $8^{o}C$ is a typical ambient air temperature during Autumn spraying and $16^{o}C$ is a typical Spring air temperature. Table C.1, Appendix C, shows typical air temperatures recorded at the Royal Agricultural College, Cirencester. $32^{o}C$ was used as an extreme to demonstrate the effect of temperature on density and viscosity, which would be of interest to sprayer operators in other parts of the world. The pesticide temperatures were maintained at +/-1 ^{o}C by means of hot or iced water in the water bath.

Three liquids were tested, water, glyphosate and isoproturon.

Water was chosen as a standard by which to compare the pesticides. Water expands moderately when heated, having a minimum volume and maximum density at $4^{o}C$. Water was an ideal, safe medium to use during the proving of the laboratory equipment, the calibration of the injection pump and the development of a safe working routine. It should be emphasised that good laboratory practice was required, particularly as concentrate pesticide was to be pumped at 3 bar. Safe procedures included full protective clothing (face shield, coverall, apron and rubber gauntlets).

Glyphosate (Monsanto Roundup, 360g/l), a translocated non-selective non-residual herbicide was chosen as it can be used in the Autumn, Spring or Summer at a wide range of temperatures. Glyphosate is formulated as a soluble concentrate which is quite an 'oily' liquid. The recommended application rate for weed control is 4 l/ha.

Isoproturon (Hytane 500 FW, Ciba - Geigy 500g/l) is a pre or post-emergence urea herbicide for use in cereals in Autumn or Spring. Hytane is an example of a suspension concentrate and is renowned for its cohesiveness. The recommended application rate is 5 l/ha.

The injection pump cab controller was set at 5 l/ha dose level and a simulator used to set the operating parameters. The area sprayed was shown on the display. The pressure vessel was set to 3 bar operating pressure to mimic a crop sprayer working pressure and present the pump with a known back pressure. Pesticide or water was heated or cooled to the desired temperature using a water bath.

The liquid was pumped into the collection vessel until 1 ha was recorded on the area meter. The collected pesticide was weighed; the density recorded via a 1 litre measuring cylinder, and the DIN beaker and stop watch was used to record the comparative flow times.

Three replications of each combination of product and temperature were used.

3.6 WATER SOLUBLE BAGS

The water soluble bag offers many advantages to the operator, it is a 'closed system' so the risk of operator contamination is minimised and half-litre bags reduce the need for measuring equipment. A number of pesticide manufacturers offer soluble bags and regard them as the way forward for pesticide packaging. When using water soluble bags in a conventional sprayer tank or induction filling bowl a number of problems can arise when the water soluble bag fails to disperse completely. It becomes a gelatinous mass and blocks the sprayer filters or induction bowl outlet. Severe agitation for some time is required to ensure the complete breakdown of the water soluble bag. In a conventional sprayer there is a large quantity of water, (600 - 2500 litres) which can be agitated to help break down the bags.

A direct injection system pump requires the pesticide to be in a liquid form. The majority of pesticides are available as liquids and any powders or water-dispersible granules are usually pre-mixed with water before being decanted into the pesticide container or tank. The pesticide container of the Dose 2000 can be fitted with a paddle stirrer, comprising a 12-volt, 6 watt electric motor driving a stainless steel shaft with mixing paddles revolving at 510 r.p.m. The bags need to be mixed with water and stirred by the paddle stirrer until they are completely dispersed. Incomplete dispersal could result in blocking the inlet filter of the injection pump or altering the viscosity of the pesticide thus affecting the injection pump output and accuracy.

Objectives:

1. To examine the mixing effectiveness of the paddle stirrer and container design when using water soluble bags.
2. To determine the minimum stirring time and minimum quantity of water required to ensure complete dispersion of the water soluble bags containing liquid or powder pesticides.

A 30 litre pesticide container, paddle stirrer, measuring cylinder and filter assembly, DIN No.4 beaker and 0.5 litre beakers were used in the trials. The filter assembly contained a BS 50 mesh (0.3mm aperture) filter, of the same specification as the inlet filter in the injection pump. The water temperature in the trials was 15^{o}C.

The trials assessed the dispersion of the bags using four methods:

Method A: A visual assessment of disintegration was made using a score 0 - 5, as described by Ickeringhill (1985). A score of 0 represented a clear liquid, free of lumps and no paddle shaft wrapping. A score of 5 represented a very large lump of bags wrapped around the shaft of the paddle stirrer due to incomplete dispersal of the bags in water.

Method B: The time taken for the mixed solution to pass through the mesh inlet filter into 0.5 litre beakers.

Method C: The time taken for the mixed solution to pass through a DIN No.4 beaker (100 ml running through a 4mm hole). The beaker was used for comparative testing of viscosities.

Method D: The amount of deposit (pesticide and bag remnants) found on the filter after 3 litres had passed through it. The inline filter at the base of the measuring cylinder was weighed at the start of the tests. At the end of each test the filter was dried in an oven at 65^{o}C for 18 hours and re-weighed to indicate the weight of soluble bag blocking the filter.

Three trials were carried out:

3.6.1 Empty water soluble bags and water: Trial A

Empty water soluble bags were placed into 3 litres of water in the pesticide container and the stirrer switched on. The contents were stirred for 5 minutes (Trials A.1 and A.2) and 2.5 minutes (Trials A.3 and A.4). A visual assessment of disintegration was made using a score between 0 - 5. The contents of the container were placed into a calibrated measuring cylinder and drained via the inline filter into a number of 0.5 litre beakers. The time taken to fill each beaker was noted using a stop watch.

Filtration tests were carried out after stirring the contents for 5 minutes and 2.5 minutes. Tests were replicated three times.

Trial A 1:1 bag in 0.5 l of water,5 mins of stirring (6 bags)

Trial A 2:1 bag in 1.0 l of water,5 mins of stirring (3 bags)

Trial A 3:1 bag in 0.5 l of water, 2.5 mins of stirring (6 bags)

Trial A.4: 1 bag in 1.0 l of water, 2.5 mins of stirring (3 bags)

Trial A.5: Clean water only through the filter (Control)

3.6.2 Bags containing liquid pesticide and water: Trial B using Oxytril CM (bromoxynil and ioxynil)

Oxytril CM is a herbicide for use on cereals and the recommended rate is 2-4 bags/ha. Each bag contains 0.5 litre of pesticide.

1.5, 2.0 or 3 litres of water was placed in the pesticide container, covering the lower mixing paddles.

Trial B 1:1 bag in 0.5 l of water, 5 mins of stirring
(3 bags) Total: 1.5 l of product, 1.5 l of water

Trial B.2: 1 bag in 1 l of water, 5 minutes stirring
(2 bags) Total: 1 l of product, 2.0 l of water

Trial B.3: 1 bag in 1 l of water, 5 minutes stirring
(3 bags) Total: 1.5 l of product, 3.0 l of water

A visual assessment along with the filtration and beaker test was carried out as described in Trial A.

3.6.3 Bags containing granular pesticide: Trial C using EXP4475 (Ranger) and water

EXP4475 (Ranger) is a wettable powder containing benazolin and dimefuron being developed as herbicide for winter oil seed rape and the recommended rate is 3-5 bags/ha. Each bag contains 0.5 kg of wettable powder.

3, 4 or 6 litres of water was placed in the pesticide container, covering the lower mixing paddles.

Trial C 1:1 bag in 2.0 l of water, 5 mins of stirring
(3 bags)(a & b)Total: 1.5 kg of product, 6 litres of water

Trial C.2: 1 bag in 1 l of water, 5 mins of stirring
(3 bags) Total: 1.5 kgs of product, 3 l of water

A visual assessment along with the filtration and beaker test was carried out as described in Trial A.

3.7 A SIMPLE FLOW DETECTOR: MILK

Objectives were:

1. To devise a safe, simple method of calibrating pipe volumes for the controller specifications 15.1 and 15.2.

2. To compare the "milk test" results with the results found in the laboratory, Section 4.3.1 and in the field, Section 4.8.1.

When commissioning an injection system on a crop sprayer, the fitter needs a simple method of calibrating the sprayer pipe volume from the mixing chamber to the first and last nozzles. The pipe volume can be calculated using pipe length and diameter, but difficulties can be encountered when trying to follow pipe runs and junctions; an alternative method is required that is safe and easy to use. Milk is available on many farms, is safe to use, and is highly visible when injected into water. A test was carried out to assess its suitability as a simple on-farm method for calibrating the pipe volume.
The in-cab electronic injection pump controller has to be programmed with various specifications of the sprayer, (Table B.1 in Appendix B). Specifications 15.1 and 15.2 require the sprayer pipe volume, from the mixing chamber to the first and last nozzles on the boom to be calculated. The 'fill routine', described in Appendix B is a method of priming the injection pump, the mixing chamber and the sprayer pipes at the beginning of spraying a field. The

'fill routine', based on the volume of the pipes and the dose level required, operates the injection pump for a number of seconds, thus priming the system with pesticide.

The sprayer was operated via the speed simulator, with clean water. The nozzle outputs were checked with a stopwatch and measuring vessel; each nozzle gave 1.45 l/min.approx. A 5 litre measuring cylinder, partially filled with milk, was fitted to the side of the injection system and a pipe from the measuring cylinder via the injection pump and mixing chamber was primed with milk using the 'fill routine'.

The main water pipelines of the sprayer were flushed through with clean water to ensure the system was thoroughly cleaned.

One litre of milk was pumped into the mixing chamber using the injection pump and the calibrated vessel. The mixing chamber has a capacity of 2 litres with the exit hole being central. One litre represents a half-full mixing chamber with minimum overflow from the chamber. The sprayer was turned on, and the delays before milk appeared were recorded at the first and last nozzles. The trial was replicated three times.

3.8 FIELD TRIALS

Previous tests based upon laboratory work need to be confirmed under field conditions. The flowrate calculations need to be proved and the laboratory tests, using potassium permanganate ($KMnO_4$) and milk need to be evaluated under field conditions. Field trials with changing conditions such as operator and sprayer performance, wheel slip and boom bounce will give a more realistic appraisal of the injection system.

3.8.1 Application of herbicides on grass

Objectives were:

1. To observe the effectiveness of the sprayer before taking it for trials on the commercial crops of the College farms.
2. To compare the injection system with a conventional sprayer when applying herbicide.

The laboratory tests had indicated that the system performed well, and to avoid damaging commercial field crops, the College sports field was to be used for the first field trial. Daisies were a problem on the perennial ryegrass of the sports field. The crop walker advised an application of the herbicide 2,4-D at 2.8 l/ha in 200 litres of water. The sprayer was calibrated at 2.8 l/ha using water and the area meter set to zero.

3.8.2 Application of herbicides on fodder beet

Objectives were:

1. To compare the effectiveness of the injection sprayer with a conventional sprayer for applying herbicides.

2. To evaluate the performance of the injection system at applying both liquid and dispersible granular pesticides.

The College farm grew 9 ha of Fodder Beet, with the variety Vermon sown on the 23rd April following a crop of winter barley. The seed rate was 125,000 seeds/ha and was precision drilled in three blocks. The middle block was to be used by the conventional sprayer and the two outer blocks of 2.5 ha each were to be used for the injection sprayer.
The Hardi sprayer was used in the injection mode as described earlier, and for the conventional trial pesticides were put in the main tank. This gave the advantage of using the same tractor and sprayer combination for both trials.

The crop showed signs of weed development within a week of drilling, the principal species being Pansy (*Viola arvensis*), Fumitory (*Fumaria officinalis*) and Black Bindweed (*Polygonum convolvulus*) with patches of volunteer barley and couch grass (*Elymus repens*).

The crop walker recommended the following products:

chloridazon + ethofumesate (Spectron)
metamitron with an adjuvant (Goldtix WG)
phenmedipham (Betanal E)
ethofumesate (Nortron)

The ability of the injection system to pump and mix pesticides of differing viscosities was noted. The quantities of pesticide used were compared with the application rate set on the in-cab controller and with the original calibration trials carried out using water.

3.8.3 Application of fungicides on cereals

Objectives were:

1. To evaluate the effectiveness of the injection sprayer at controlling disease on winter cereals.

2. To compare the injection sprayer with a conventional sprayer.

Three trials were devised for two fields of winter cereals:

Trial A was a 8.15 ha field of winter barley, the variety Gaulois. At growth stage 49 mildew (*Erysiphe graminis*) was noted and the crop walker recommended an application of: fenpropimorph (Corbel) and propiconazole (Tilt 250 EC)

The field was sprayed with the injection sprayer and three areas were marked out to remain untreated. Leaf observations were made to assess disease control.

Trial B was carried out in a 15.75 ha field of Gaulois winter barley at growth stage 55 when *Rynchosporium* and brown rust (*Puccinia spp.*) were noted. The crop walker recommended:
propiconazole + tridemorph (Tilt Turbo 475 EC)

The field was sprayed in a number of areas:

part a remained untreated

part b was sprayed with the injection system

part c was sprayed with a conventional sprayer.

The flag leaf was inspected for signs of disease control at four day intervals following spraying.

Trial C was the monitoring of Septoria and brown rust (*Puccinia spp.*) control on a 14 ha field of Slejpner winter wheat. The crop walker recommended:

propiconazole (Tilt 250EC)

The field was split into similar blocks to Trial B and the trials were replicated three times.

3.9 SPOT TREATMENT OF WEEDS USING PARAQUAT ON GRASS

Objectives were:

1. To prove the mathematical analysis and evaluate the results of the potassium permanganate and milk tests.

2. To show that the distance the sprayer travels after the injection pump is switched on but before pesticide appears at the boom nozzles, is equal to the distance travelled to clear the boom pipes of pesticide, after the injector is switched off.

3. To demonstrate that higher application volumes per hectare result in a faster response to switching the injector on or off.

The time taken for the pesticide to reach the first and last nozzle is of interest because of patch spraying (spot treatment) of weeds. Similarly, time delays are of interest at the beginning and end of a field when the spraying operation begins or ends because any delay in pesticide reaching the boom results in an area of unsprayed field.

The spot treatment of weeds or diseased plants should lead to a reduction in pesticide use on the farm, as the pesticide is only applied when required rather than being used as an overall blanket spray.

Larger errors in pesticide application can occur if the pesticide is injected into the water near the sprayer water pump, which causes a longer delay than when the injection is made nearer the nozzles.

In the field experiment the tractor and sprayer were used on a three year ley of Italian ryegrass that was due to be ploughed in. Paraquat (Grammoxone 100) was applied at 2.5 l/ha. Tractor forward speed was 8.7 km/h. Weather conditions were ideal for spraying.

Two trials were carried out:

a) 100 l/ha application rate to measure the distance and time taken for pesticide to appear and disappear at the first and last nozzle after switching the injector on and off at the mixing chamber.

b) 200 l/ha application rate, as above.

3.10 LARGE-SCALE FIELD TRIALS AT THE WEASENHAM FARMING COMPANY

Objectives were:

1. To note the accuracy of the injection system with pesticides of varying viscosities.

2. To evaluate the performance of the injection sprayer to inject both liquid and powdered pesticides at varying application rates on different crops.

3. To investigate the component life over a period of time and detect function errors.

4. To gain information on the practical advantages of the injection sprayer as seen by a large scale farmer.

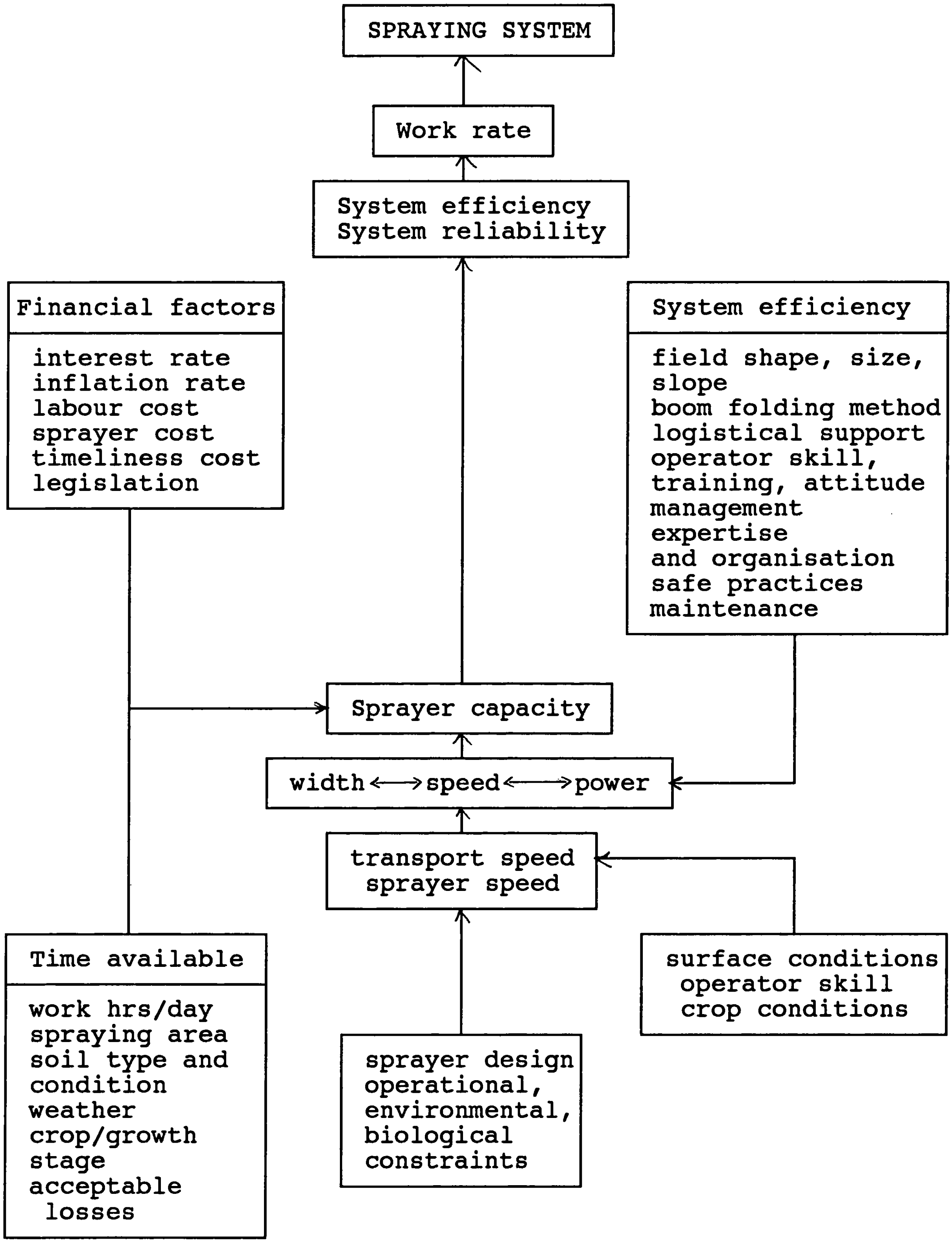
5. To consider the operator's understanding of the system.

Feltwell Farm is situated on the Norfolk/Cambridge border in East Anglia. The black peat soil is mainly at or below sea level. Three trailed crop sprayers are used on the farm and arable enterprises include:

Winter wheat: 645 ha   Sugar Beet: 252 ha   Potatoes: 301 ha
Carrots: 365 ha   Green Beans: 286 ha   Onions:40 ha
Grass:247ha.

Crop health and development was monitored and the spraying programme was devised by the arable foreman in conjunction with the farm manager. Plates 3.3 and 3.4 show the injection unit fitted to a Chafer T2000 sprayer for the large-scale field trials at Weasenham Farms.

Figure 3.2 **The components of a spraying system**



3.11 IMPROVING SPRAYING LOGISTICS

A 'spraying system' comprises many different aspects. The output of the sprayer depends on many inter-related, inter-dependent and variable factors. Figure 3.2 illustrates a 'spraying system' based on a systems analysis approach to mechanization management developed by Landers and Robson (1988). Improving spraying logistics is a small part of the efficiency of the spraying system. The major advantage of an injection sprayer is the ease of connecting the pesticide container to the side of the sprayer at the headland or farmyard and reducing the time spent washing out the sprayer at the end of the field or day's work.

Objectives were :

1. To develop a computer programme to consider the effect on sprayer output of changes in certain variable factors, e.g. increased tank size, boom size or filling time
2. To monitor any increase in the output of a spraying system after the introduction of an injection unit.

A computer programme (Landers, 1992) was developed based upon a variation of the Baltin-Amsden formula, (Matthews, 1979), and a study on mechanization planning, (Landers, 1984). The programme's details and listing are provided in Appendix D. The computer programme is used as a guide for comparing one spraying system or modification to a system with another.

Three farms were visited for two days to observe their spraying system. The sprayers' details such as tank size, boom width and application rate were noted along with the tank filling time and the time to travel to the fields. The farms studied were:

a) Kemble Estate, Glos. which uses an MB trac and Hoegen-Dikof demountable sprayer.
b) Weasenham Farms, Norfolk where a trailed Chafer sprayer and a water bowser in the field is used.
c) Stowell Park, Northleach, Glos. which uses an MB trac and a Cleanacres Airtec sprayer; the sprayer returns to the farmyard to fill with water.

3.12 PESTICIDE REMNANTS IN CONVENTIONAL SPRAYERS

As a result of applying pesticides in the field, the sprayer tank empties; when it is nearly empty, the main water pump begins to suck in air. Any pesticide remaining in the sprayer 'system' i.e. the tank, pump, valves and boom pipes could create a problem for subsequent applications, particularly to other crop types.

Objectives:

1. To measure the quantity of liquid remaining in a conventional crop sprayer 'system' after finishing spraying.

Three conventional crop sprayers were used in the test, to represent the current range of sprayers in use on farms;

each model represents a variation in tank size, pump type, boom width and pipe length and diameter:

a) Chafer T2000 trailed sprayer with a 2000 litre tank, centrifugal pump and 24m booms

b) Hardi TZ1500 trailed sprayer with a 1500 litre tank, diaphragm pump and 18m booms

c) Allman 625 mounted sprayer with a 625 litre tank, diaphragm pump and 12m booms.

Tests were carried out on each sprayer by filling the tank with water, the sprayers were operated spraying water at 2.5 bar pressure. As the sprayer began to run dry, the pressure dropped to 1 bar, and the spray pattern became erratic as air became entrained in the water from the tank. The sprayer was switched off and the amount of liquid remaining in the sprayer 'system' was collected and measured.

CHAPTER 4. <u>RESULTS</u>

4.1 ANALYSIS AND PRESENTATION OF RESULTS

The results of the laboratory experiments and field trials have been presented in the form of tables, graphs or bar charts.

Statistical analysis was applied to the results, using methodology described by Parker (1973). Regression analysis used to obtain the slope of the graphs to enable comparison of the pump tests and standard deviation reflected the dispersion of values obtained in the trials. Changes in concentration levels were compared using coefficient of variation. Analysis of variance was used for the field trial results using Student's t statistical tables. In all tests, three replications were made.

4.2 THE LINEARITY OF PUMP OUTPUT

Accuracy during crop spraying is so important due to the costs of application, materials and the effect on the crop of over and under application. Environmental problems associated with excessive pesticide use must also be considered.

Regression analysis was used to obtain the slope of the graphs (inclination coefficient) to enable comparison of the pump tests. The output intercept of the x axis was noted as being step zero with zero output.

4.2.1 Pump output using a belt and pulley drive

Figure 4.1 shows the results of the three water tests carried out on pump number one - output against step number. Table C.2, Appendix C, summarises the results of the three water tests and Table C.3, Appendix C, shows a summary of the statistical analysis.

The results from tests 1 and 2 show how linear the pump output is at various output settings (step numbers) until step number 1800 when the output drops; a similar effect is seen at step 1400 on test 3. The piston stroke length increases as the step number increases resulting in an increase in torque in the driving mechanism. The pump was driven via a belt and pulley system from the tractor power take off and the increase in torque may have led to belt slip. The belt slip was so great that the original results from test 3 should be ignored.

Regression analysis shows that the slope of the graph (inclination coefficient) (Table C.3, Appendix C) was similar between tests 1, 2 and the modified test 3, being 7.8, 7.15 and 6.83 respectively. The steeper the slope, the greater the flow.

Figure 4.1 PUMP OUTPUT: DRIVE BELT

Water: litres/hour

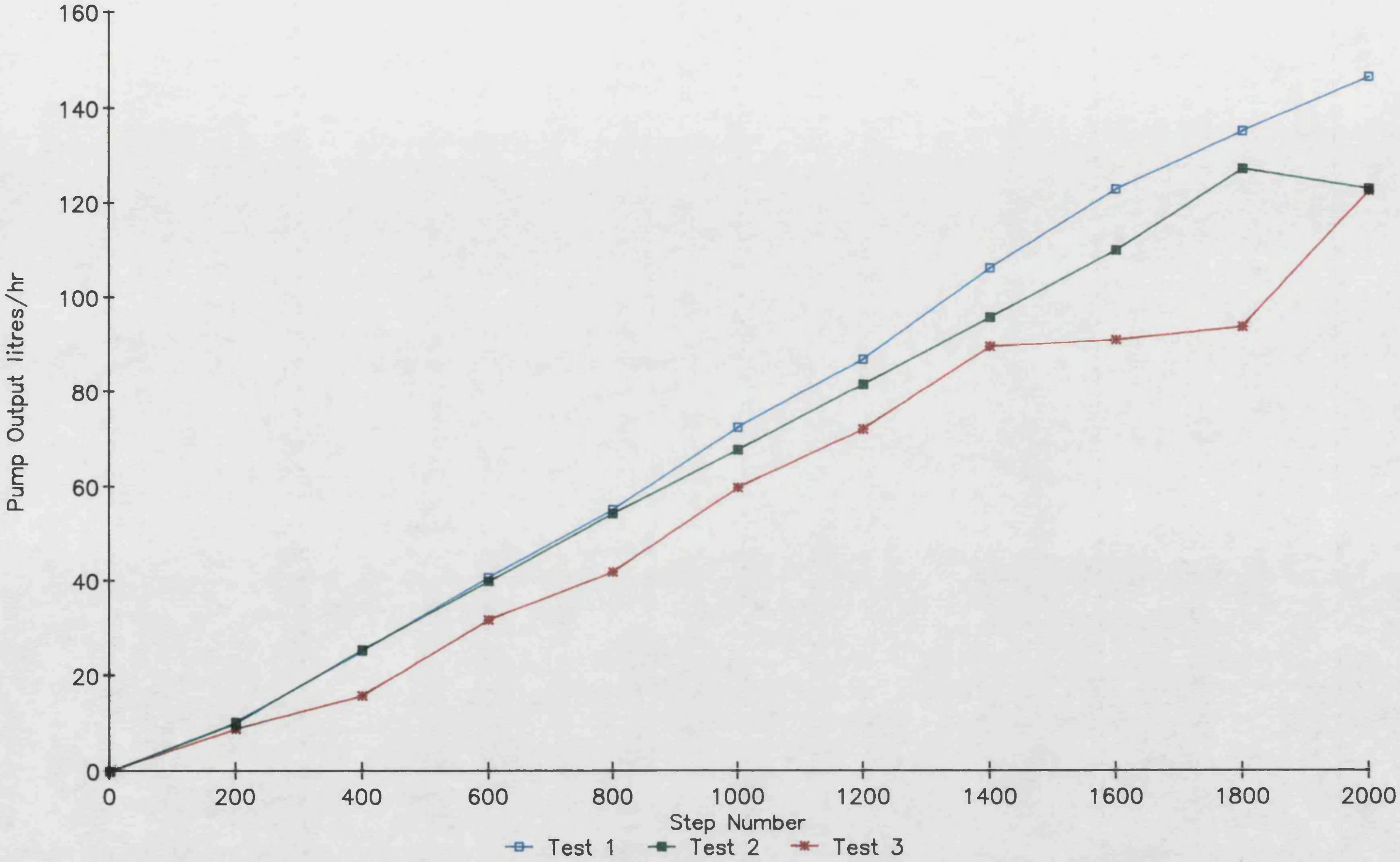


Figure4.2 PUMP OUTPUT:HYDRAULIC DRIVE

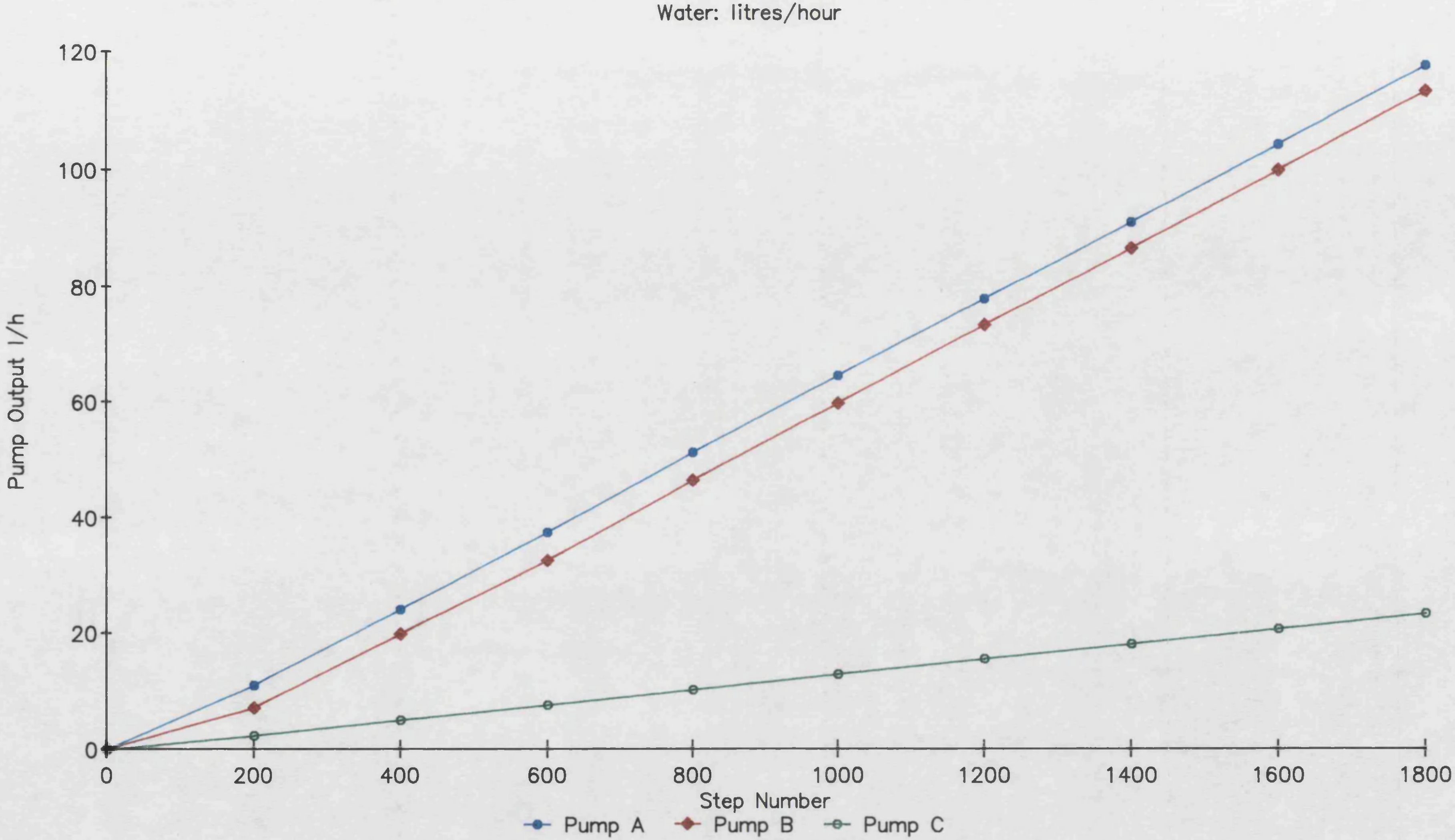
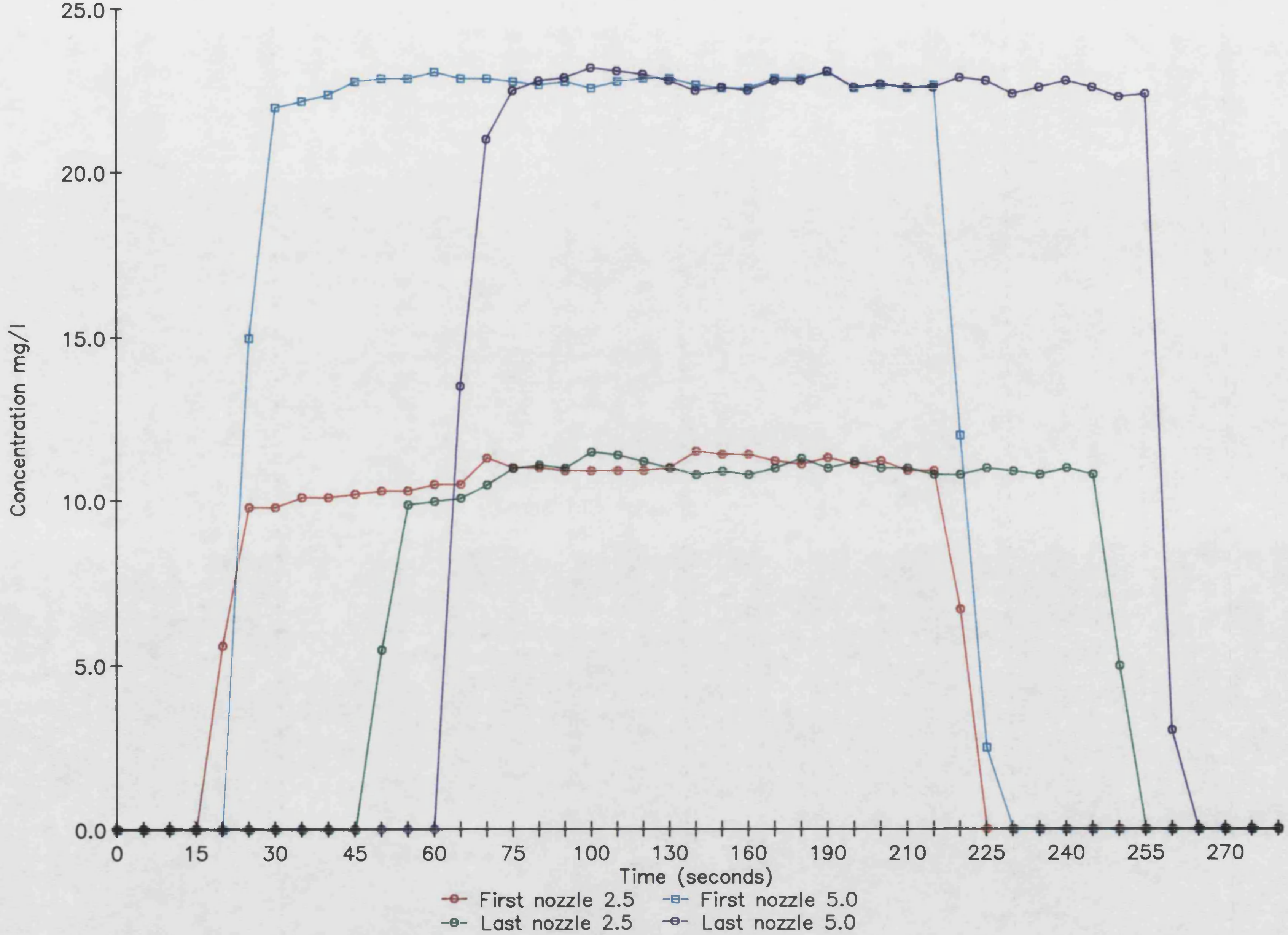


Figure 4.3 BOOMFLOW TEST No.1

Uniformity of conc. between nozzles



4.2.2 Pump output using a hydraulic drive

Section 4.2.1 shows that pump output was affected by belt slip, particularly at high dose rates. The recommendation of a toothed belt or hydraulic motor drive needs to be evaluated to see if the positive drive of the hydraulic motor produces better linearity at all dose settings. Figure 4.2 shows the results, output against step number. Table C.4, Appendix C, summarises the results of three water tests with two standard (pumps A and B) and one small pump head (pump C).

The tests show that pump output was very linear. The pump output was not affected at the longer stroke lengths (higher step number) and the use of a hydraulic motor to drive the pumps had overcome the problems associated with drive belt slip. The two standard pump heads (pumps A and B) show very similar outputs, but from step 0 to step 200 they do not follow the same line as from step 200 - 1800. Therefore, at low dose rates, it is better to use the small pump head to obtain accuracy. Regression analysis Table C.5, Appendix C, shows the slope of the graph (inclination coefficient) was the same for both standard pumps, pump A being 6.67 and pump B 6.66.

4.3 BOOM FLOW CHARACTERISTICS

Pesticide and water combine in the mixing chamber and further mixing occurs via the pipes and junctions of the sprayline. The time taken for pesticide to reach the first and last nozzles needs to be assessed as any delay could result in an area of crop remaining unsprayed. Figures 4.3 - 4.7 show the results as graphs, concentration against time, but note that concentration levels in all the graphs for the 5.0 l/ha settings should be 25 mg/l but are only 23 mg/l due to belt slip reducing pump output. The belt slip has a similar effect on the other pump settings. Tables C.6 - C.10, Appendix C, show the results obtained from the tests and Table C.11, Appendix C, contains a summary of the statistical analysis.

4.3.1 Uniformity of concentration between the nozzles during constant injection

The objective of this test was to determine if adequate mixing occurred so that the pesticide was uniformly distributed between the first and last nozzle.

Two tests were carried out, at 2.5 l/ha and 5.0 l/ha in 100 litres of water, samples being taken at the first and last nozzles on the boom, Table C.6, Appendix C.

Figure 4.3 shows the results of the trial. Table C.11, Appendix C, shows a coefficient of variation of 4% at the shorter pump stroke of 2.5 l/ha and 1.5% at the longer pump stroke of 5.0 l/ha.

Figure 4.4 BOOMFLOW TEST No.2&3

Uniformity of mixture concentration

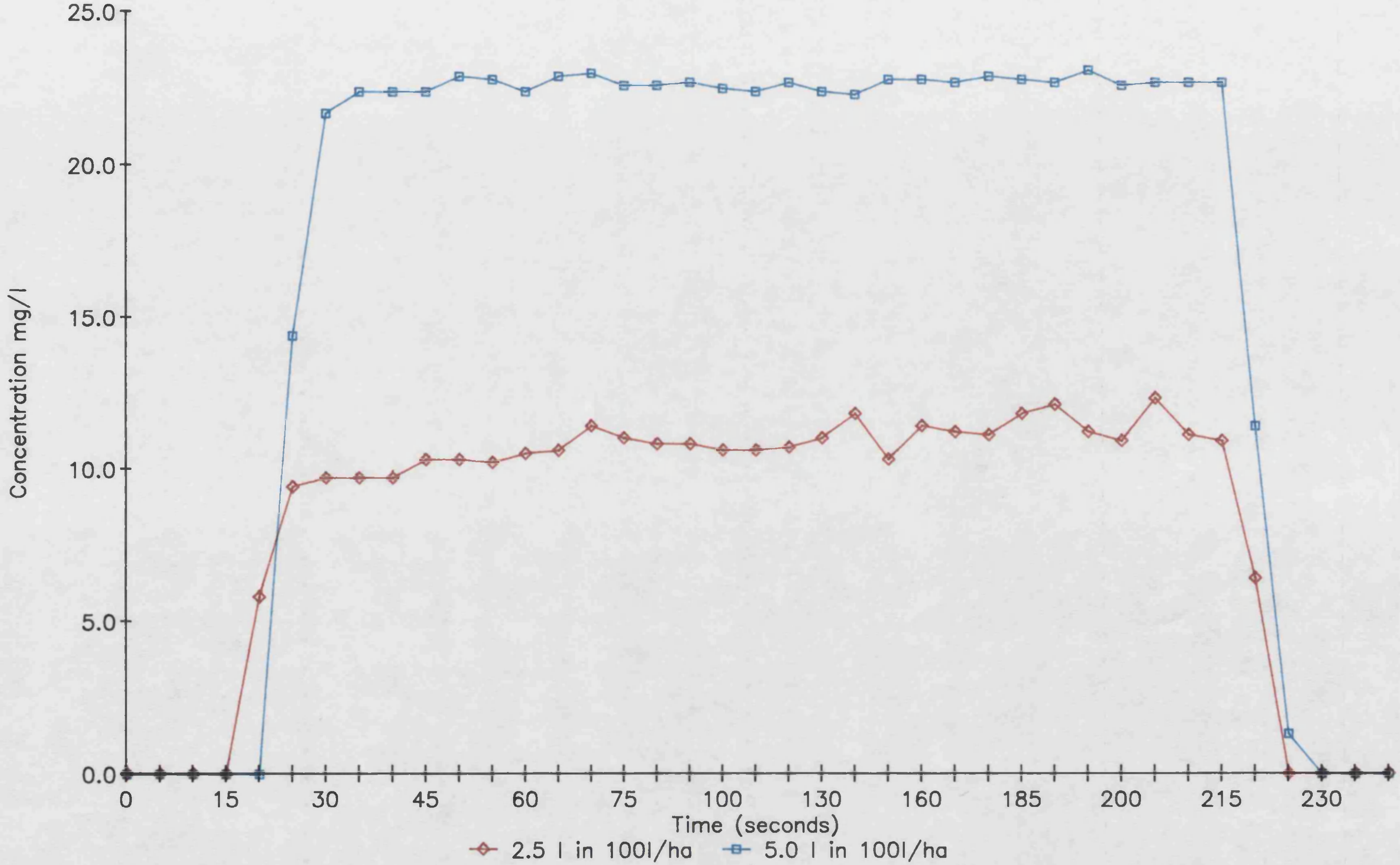
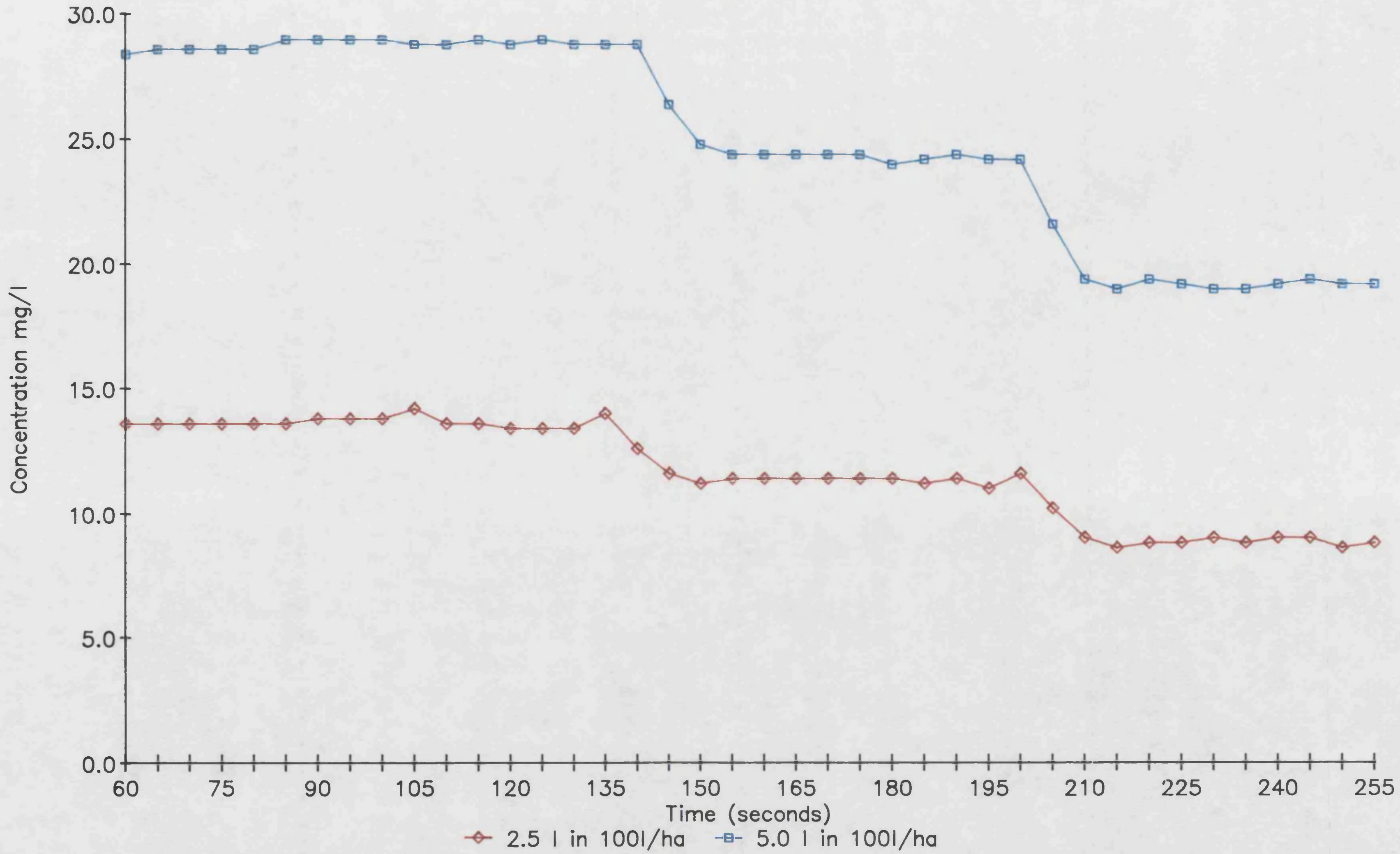


Figure 4.5 BOOMFLOW TEST No.4

System response: tractor speed change



The results indicate that there is very little variation in concentration levels between the first and last nozzle. The mixing chamber and sprayer pipe length ensure a very good mixing of tracer and water.

4.3.2 Uniformity of mixture concentration as a function of time

The objective was to determine if the injection pump could meter the pesticide at a constant rate. If the pump produced a pulse flow, stripes would occur in the field due to the ripple effect.

Two tests were carried out, at 2.5 l/ha and 5.0 l/ha in 100 litres of water, Table C.7, Appendix C. At the 2.5 l/ha setting the pump has a short stroke compared to the longer stroke at 5.0l/ha.

Figure 4.4 shows the results of the two tests using short and long piston strokes. The results show there are no major variations in concentration levels with time. Whilst the injection pump does create a pulsed flow (due to the reciprocating action of the piston in the cylinder), the action of the mixing chamber and the distance of the pipes to the nozzles ensures a thorough mixing of the tracer with the water. The graph shows the minor variations, particularly at the 2.5 l/ha level.

Table C.11, Appendix C, shows that a greater coefficient of variation occurred during the shorter pump stroke of 2.5

litres (6.29% variation) compared with the longer pump stroke at 5.0 litres where only 1.39% variation occurred.

4.3.3 Transient Time

The objective of this test was to determine the delay time of the pesticide reaching the nozzles. This situation would arise when using the sprayer for the spot treatment of weeds.

Two tests were performed, at two dose levels of 2.5 l/ha and 5.0 l/ha in 100 litres of water. In the first test data acquisition and injection were started simultaneously to see how long it took for the desired concentration to reach the first nozzle. In the second test data acquisition began after the injection was terminated, thus recording how long it took for the spot treatment to finish, Table C.7 Appendix C.

The sprayer hose had a capacity of 11.6 litres between the mixing chamber and the first nozzle.

Figure 4.4 shows that it took 20 seconds for the tracer to be detected at the first nozzle, 25 seconds before the desired concentration was attained at a dose level of 2.5 l/ha and 25 seconds and 30 seconds respectively at 5.0 l/ha. Test 1 (Figure 4.3) shows it takes 30-40 seconds longer for the tracer to reach the last nozzle due to the pipe volume between the point of injection and the last nozzle. The second test was carried out to monitor the time taken for clean water to reach the nozzles.

Figure 4.4 shows that it took 45 seconds at 2.5 l/ha and 5.0 l/ha for the boom line to be purged to the first nozzle. As in the previous test, this time delay would result in a long distance to travel in a field situation to clear the booms of pesticide. It is interesting to note that whilst it took only 25-30 seconds for the tracer to reach the first nozzle, it took 45 seconds to remove all traces. The explanation for this could be that the pump takes time to stop and that the tracer may well stick to the sides of the pipes. Further tests need to be carried out with different viscosity pesticides to monitor pipe surface retention characteristics.

The results obtained in this section should be compared with the results in sections 4.9 and 4.13. Section 4.9 shows the results of field trials where paraquat was applied to grass and the time delay of pesticide to reach the nozzles was measured and section 4.13 shows a calculation of flow rates and time for liquid to reach the nozzles.

4.3.4 Response of the injection system to tractor-speed changes

The objective of this test was to monitor the time taken to effect a change in concentration due to a change in pump output to compensate for a change in forward speed.

Tractor forward speed was adjusted by 20% and then a further 20% by means of a simulator. Trials at 2.5 l/ha and 5.0 l/ha were carried out with the tractor speed of 10.8km/h being reduced by 20% to 9.0km/h and by another 20% to 7.2km/h, Table C.8 Appendix C.

Figure 4.5 shows the results of the changes in speed. The graph shows how constant the injection pump output was at 10 km/h and that it took about 30 seconds to change the concentration level after a change in forward speed to 9.0 km/h; a similar pattern occurred when the speed changed to 7.2 km/h. As with Test 3, the time delay would result in a long distance being travelled before the required concentration level was attained. Table C.11, Appendix C, shows that a coefficient of variation of approximately 2% occurs at the shorter stroke length, irrespective of speed, and a coefficient of variation of 0.04% approximately at the longer stroke lengths. The standard deviation was extremely low, again reflecting the accuracy of the pump.

Figure 4.6 BOOMFLOW TEST No.5

System response: changes in dose rate

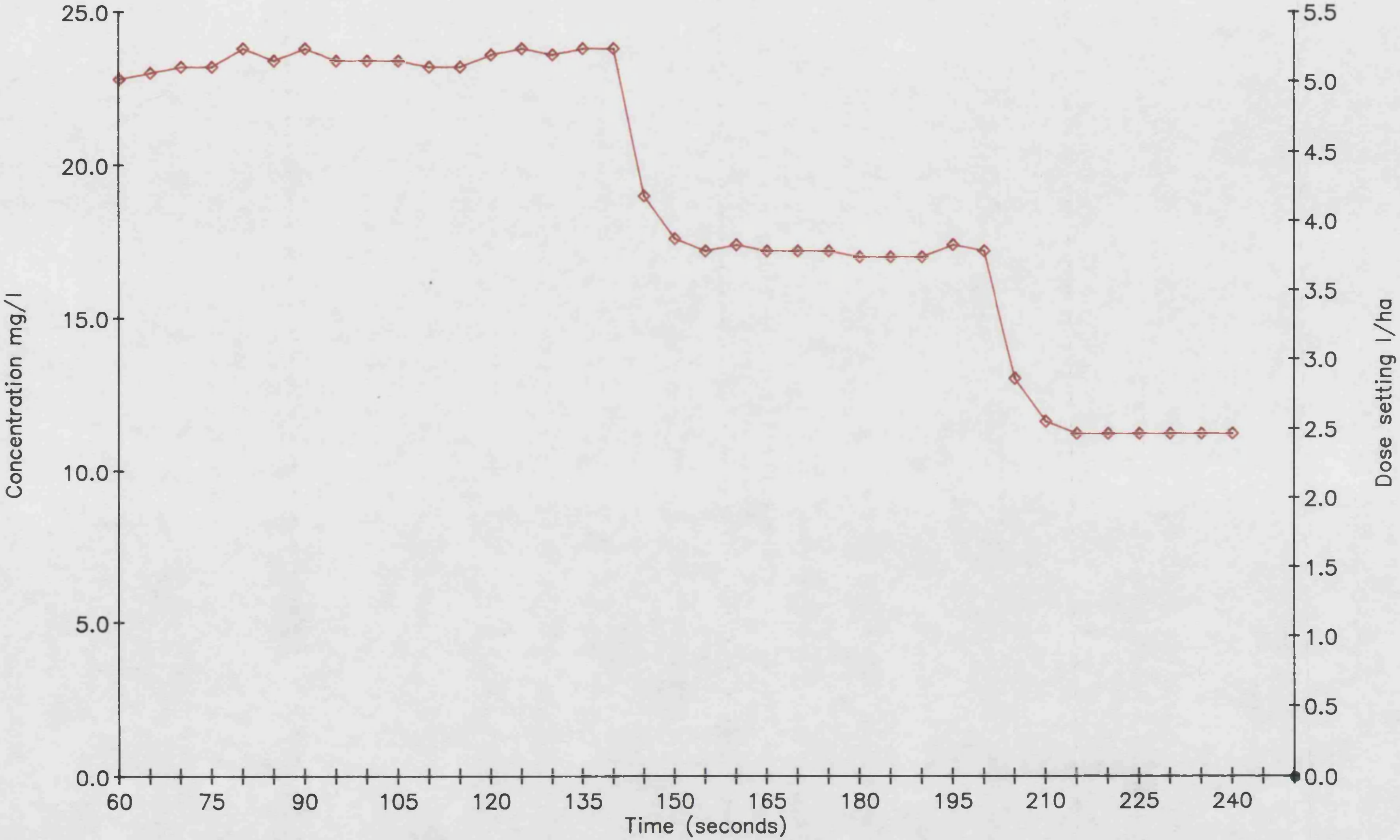
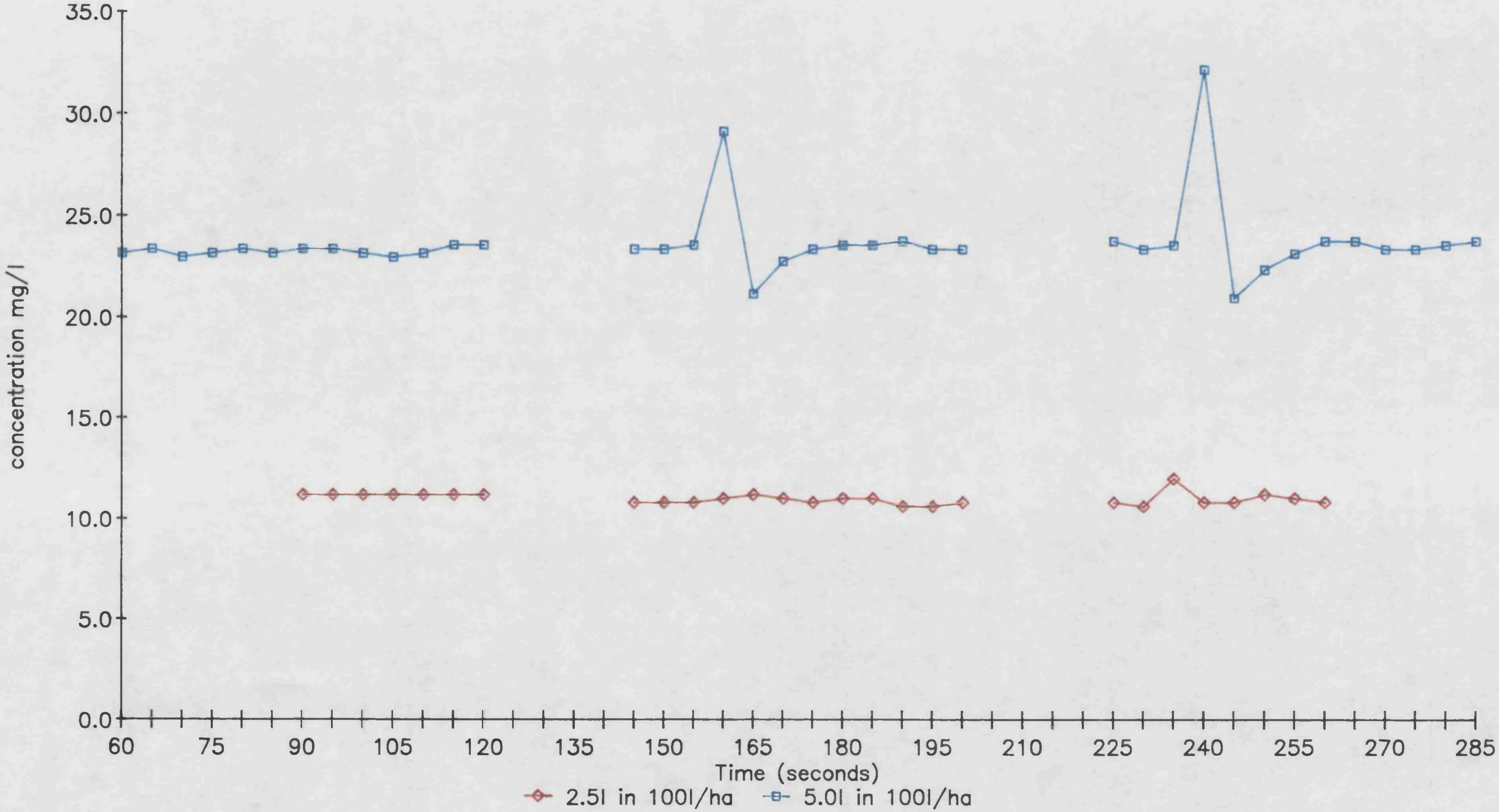


Figure 4.7 BOOMFLOW TEST No.6

System response: switching on/off



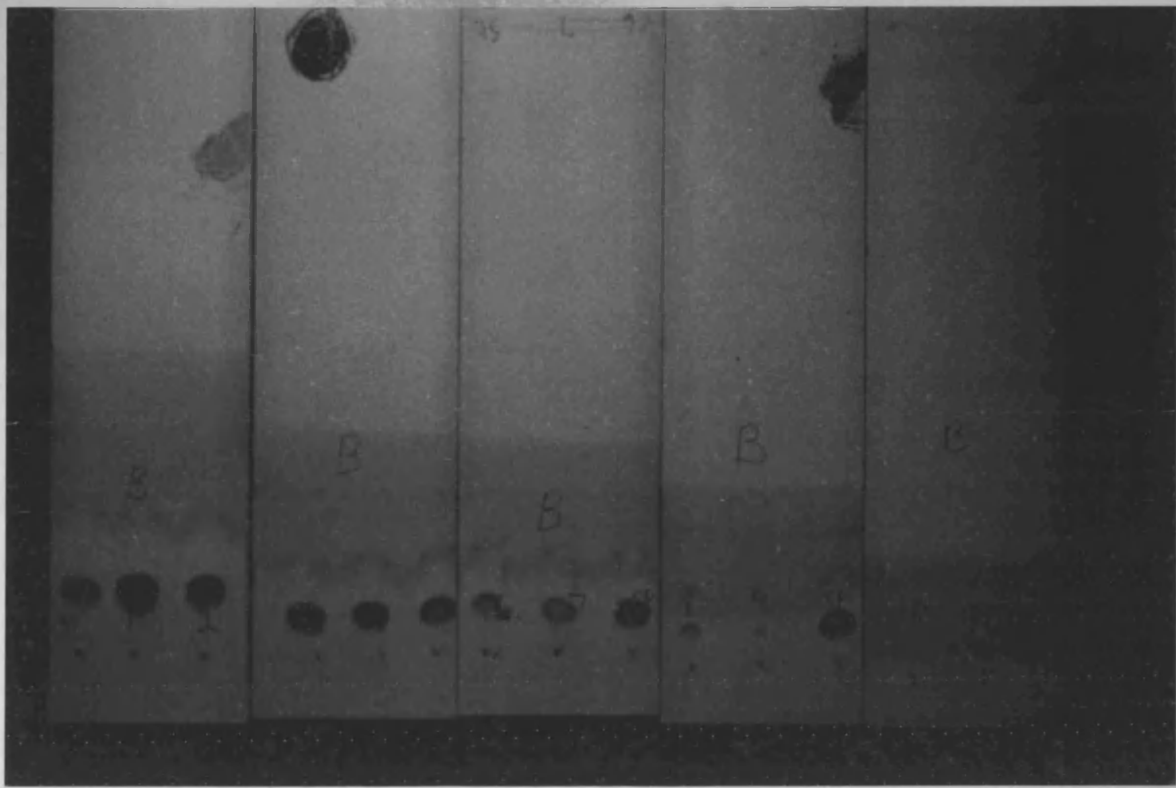


Plate 4.1 TLC plates showing sample spots obtained from the purge trials using water to remove traces of Isoproturon (Hytane).[St.=standard]

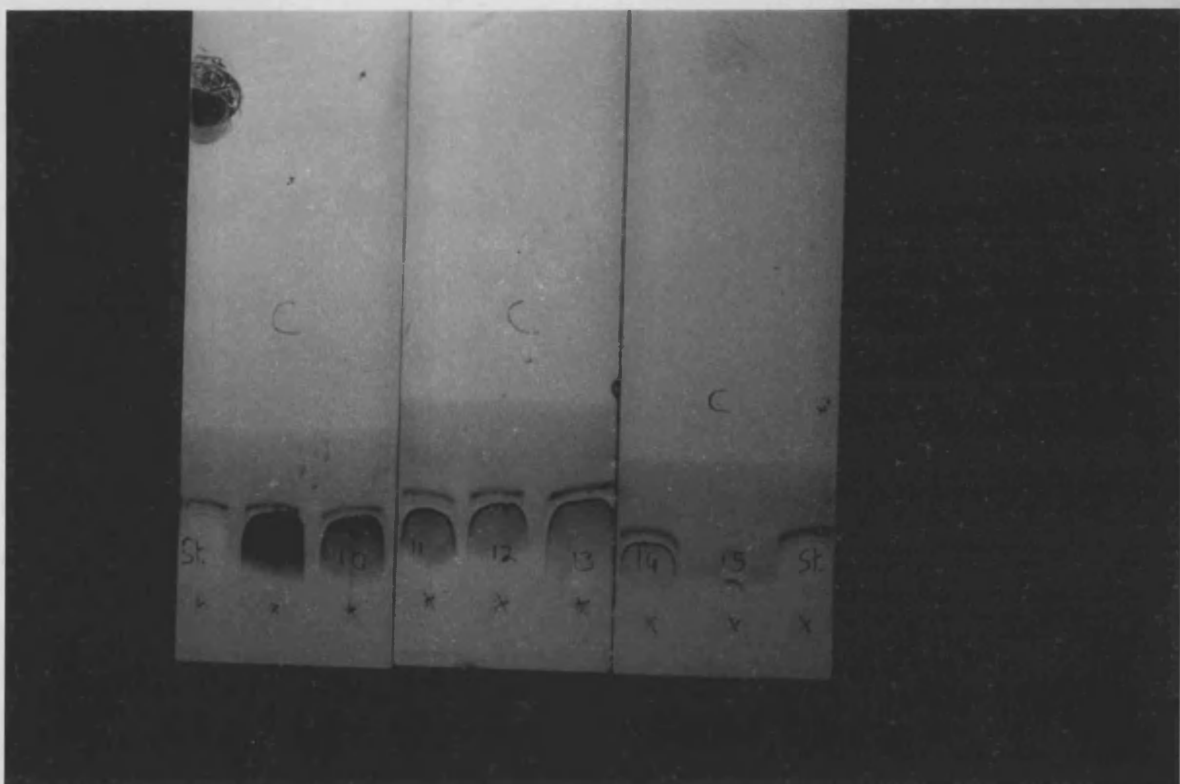


Plate 4.2 TLC plates showing sample spots obtained from the purge trials using 'Supray Spraynett' to remove traces of Isoproturon (Hytane)

4.3.5 Response of the injection system to changes in dose level

The objective of this was to monitor the time delay and concentration level after a change in dose level has been effected at the cab control box.

The dose level was adjusted by 25% and then a further 25% on the preset control box:

Dose level No 4: 5.0 l/ha

Dose level No 3: 3.75 l/ha

Dose level No 2: 2.50 l/ha

Figure 4.6 shows the results. It can be seen that the system takes about 20 seconds to respond at the first nozzle on the boom. The pump output is very consistent at each of the preset dose rates, Table C.9,Appendix C.

Table C.11, Appendix C, shows very low coefficients of variation and standard deviation at all dose levels, indicating a very accurate injection pump and electronic controller.

The advantage of being able to adjust dose rates on the move is that the operator can reduce pesticide dose on lower infestation levels, if required.

4.3.6 Response of the injection system to switching the water flow on or off

The objective was to monitor response time and concentration levels as the sprayer water flow was switched on or off, a situation that arises when turning at the field headland.

Figure 4.7 shows the results of two trials at 2.5 l/ha and 5.0 l/ha in 100 litres of water. The graph, based on Table C.10, Appendix C, clearly indicates that a rise in concentration level occurs about 15 seconds after the water flow has started again; this effect is very prominent at the higher rate of 5.0 l/ha and is an increase of approximately 29% above the mean.

When the operator switches off the water at the main control valve, the injection pump takes a few seconds to slow down to zero stroke length. This results in extra pesticide being injected into the mixing chamber. When the water is switched back on the increased amount in the chamber then goes out to the nozzles resulting in the rise in concentration level seen on the graph. The injection pump also takes a certain time to reach the desired piston stroke length to give the preset dose level, thus the graph shows the resultant dip in the concentration level. This again is much more evident at the higher dose rate (longer stroke length). Table C.11, Appendix C, shows the coefficient of variation at 7.57% at the longer stroke due to the momentary increase in concentration. Fortunately, the effect of higher and lower concentrations was sufficiently small not to be noticeable in field trials on growing crops.

4.4 SYSTEM PURGE TRIALS

The objective of this test was to monitor the purging of the sprayer pipelines of pesticide residues. The effect of small residues of some herbicides on subsequent crops can be considerable, (BCPC, 1986).

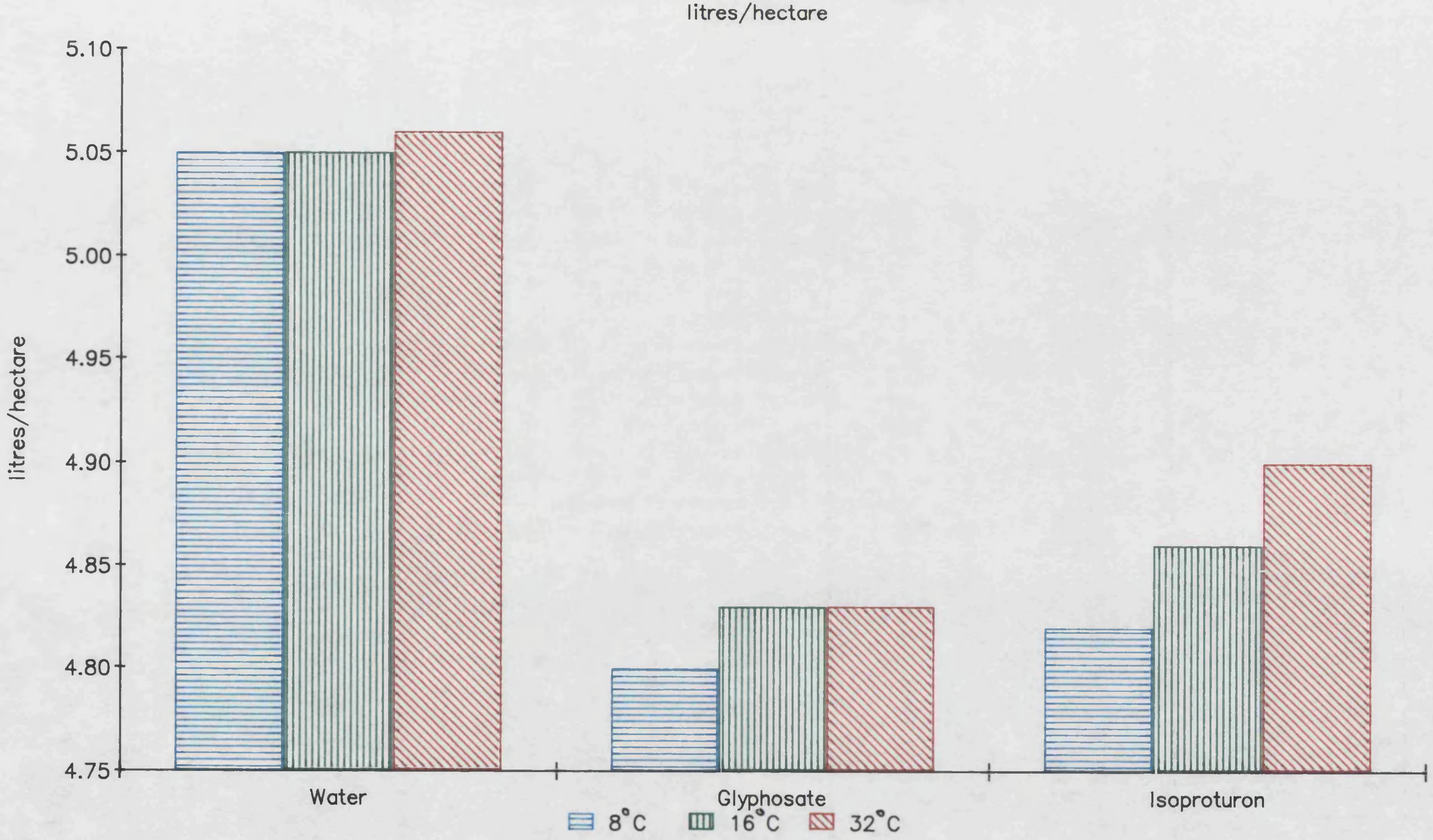
Previous tests, section 4.3.1 - 4.3.3, show the time taken to purge the system and section 4.3.3 concludes that it took 45 seconds to remove all traces of potassium permanganate ($KMnO_4$).

Isoproturon (Hytane) was used as it is a cohesive pesticide and Thin Layer Chromatography used to analyse the wash solution collected after flushing water or 'Supray Spraynett' through the injection system.

Plates 4.1 and 4.2 show the collected samples compared with the standard solution on the TLC plates. Each numbered spot refers to a 500ml sample of wash solution and the spots marked St. refer to the standard solution. Table C.12, Appendix C, compares the quantity of wash solution with the solution spots on the TLC plates.

The TLC plates indicate that it took 7.2 litres of water and 5.2 litres of 'Supray Spraynett' to flush all remnants of Isoproturon (Hytane) from the valve, pipes and pumphead. A visible colour change in the sample beakers occurred much earlier in the purge trials; after flushing with 3.7 litres of water or 2.7 litres of 'Supray Spraynett'. The results show that at an application rate of 2.5 l/ha the sprayer would cover 3.0 ha before the booms were clear of pesticide if water was used to flush the injection system.

Fig.4.8 PUMP OUTPUT WITH 2 PESTICIDES



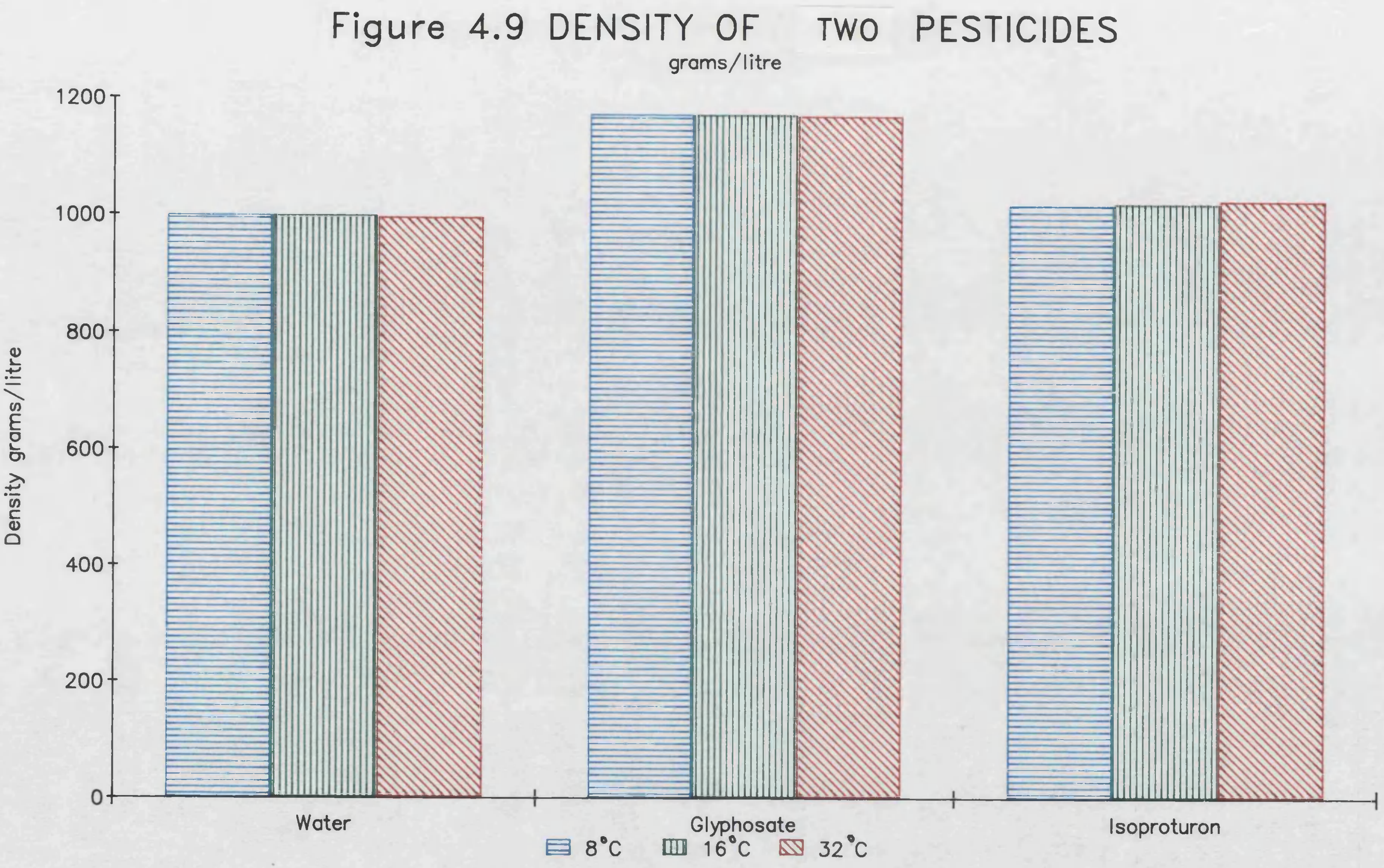


Figure 4.9 DENSITY OF TWO PESTICIDES
grams/litre
1200
1000
800
600
400
200
0
Density grams/litre
Water
Glyphosate
Isoproturon
8°C
16°C
32°C

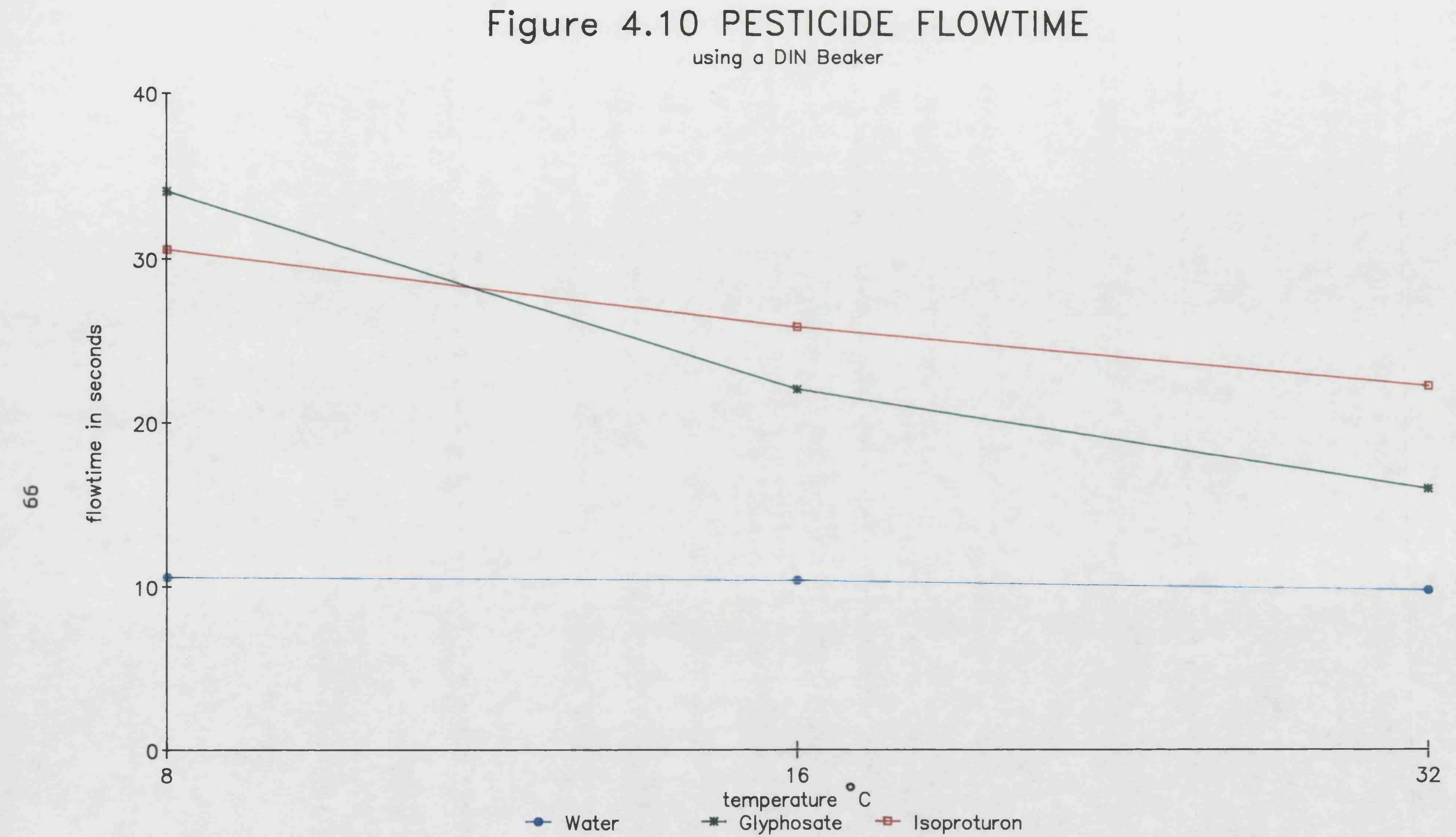


Figure 4.10 PESTICIDE FLOWTIME
using a DIN Beaker
40
30
20
10
0
flowtime in seconds
8
16
32
temperature °C
Water
Glyphosate
Isoproturon

4.5 METERING PESTICIDES OF VARYING VISCOSITIES AT DIFFERENT TEMPERATURES

The objective of this test was to determine the effect of pesticide formulation and temperature on the metering accuracy of the injection pump.

Figure 4.8 shows the mean pump output for two pesticides and Figure 4.9 shows the density of the two pesticides at three temperatures. The pesticide flow-times are shown in Figure 4.10.

The pump was calibrated using water at 16^{o}C. The cab controller was set at 5.0l/ha (this being the recommended rate/ha for Isoproturon (Hytane)). All trials were carried out based upon this original setting.

It is evident from Figure 4.9 that the flow rate of water from the pump at all three temperatures tested (8^{o}C, 16^{o}C and 32^{o}C) varied by a very small margin of 1% above the target rate.

When Glyphosate was used, at the pre-set dose level of 5 l/ha, the pump was very consistent in its accuracy, at three temperatures the output was constant throughout, although the output was 3.4% below target. The density, Figure 4.9, remained reasonably constant although the flow time through the DIN beaker reduced by 50% as the temperature changed from 8^{o}c to 32^{o}c.

Glyphosate, an oily substance, behaved like water, although the flow time through the beaker changed considerably, Figure 4.10. A slight adjustment, 3.4%, to the cab controller would allow the chemical to be applied accurately at all temperatures.

The density of Isoproturon remained fairly constant, 1067 grams/litre between 8^{o}C and 32^{o}C. The flow time through the DIN beaker decreased by 20% as the temperature increased from 8^{o} to 32^{o}C. Plate 3.6 shows the DIN beaker being used to measure the flow time of Isoproturon. The pump output was consistently below target at all the temperatures tested, at 32^{o}C, pump output was 2% below target and at 8^{o}C inaccuracy rose to 3.6%. Plate 3.7 shows the injection pump, remote control and the cab controller being used to pump Isoproturon at various temperatures.

Tables C.13-C.15, Appendix C, shows that pesticides flow at different rates, depending on temperature and formulation. Glyphosate becomes very viscous at low temperatures, but at higher temperatures viscosity is reduced.

The pump was capable consistently of injecting pesticides of varying viscosities and densities at different temperatures, but to ensure the correct application rate, the injection pump must be calibrated according to the pesticide formulation and temperature.

Figure 4.11 WATER SOLUBLE BAG TRIALS

Oxytril & water: filter test

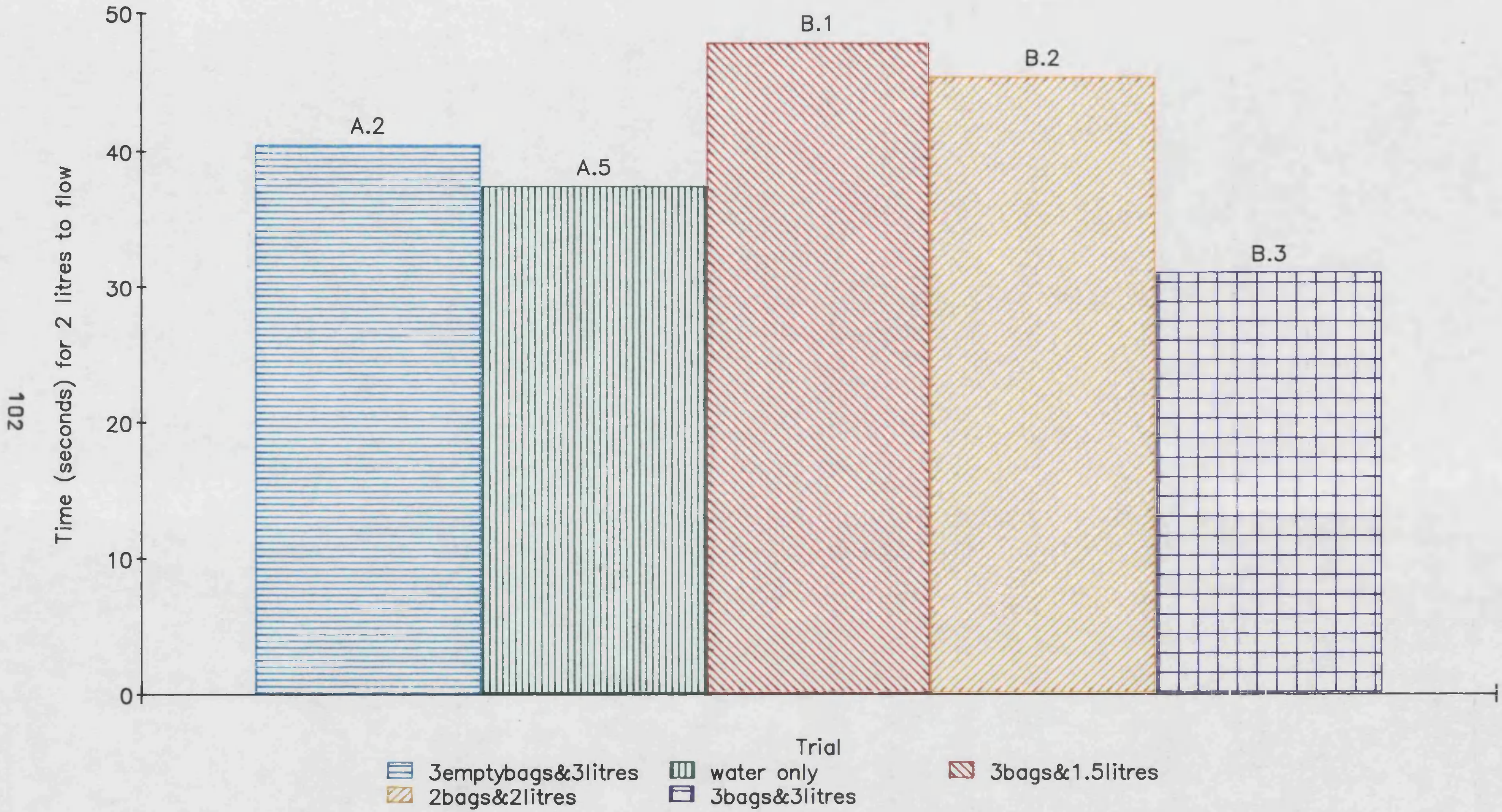


FIGURE 4.12 WATER SOLUBLE BAG TRIALS

EXP4475 Ranger & water: filter test

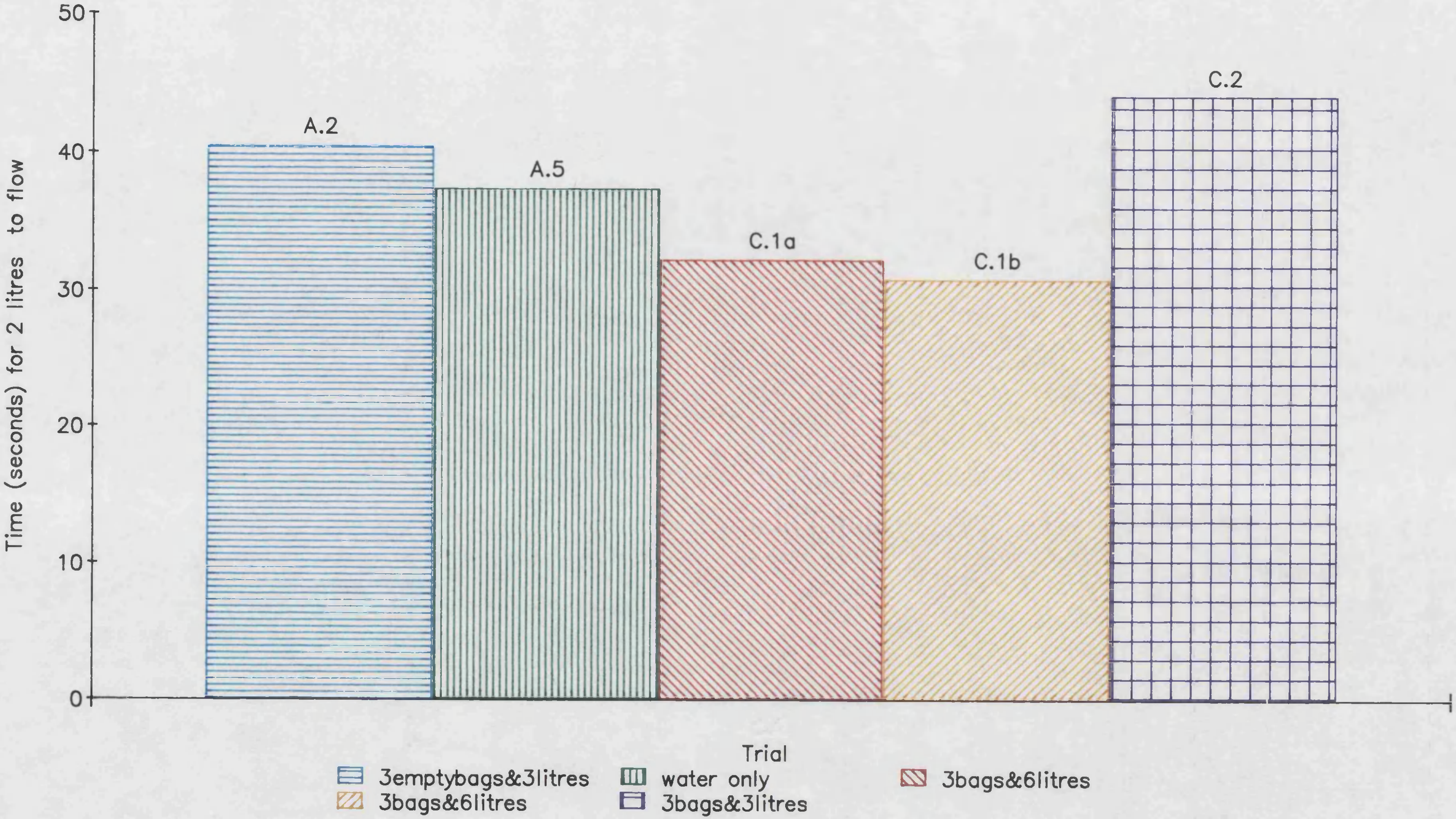


Table 4.1 **Nozzle output/pipe volume**

First Nozzle

Test No.	Time (seconds)	Flow rate (litres/second)		Output (litres)
1	11.8	x 0.96	=	11.33
2	12.0	x 0.96	=	11.52
3	12.2	x 0.96	=	11.71
			Total	34.54
			Average	11.50

Last Nozzle

Test No.	Time (seconds)	Flow rate (litres/second)		Output (litres)
1	27.1	x 0.96	=	26.02
2	26.8	x 0.96	=	25.73
3	27.3	x 0.96	=	26.21
			Total	77.96
			Average	25.99

Based upon:
Average nozzle output:1.45 litres/minute at 200 litres/hectare
20 metre boom, nozzles at 0.5m spacing
40 nozzles x 1.45 litres/minute = 58 litres/minute divided by 60 = 0.96 litres/second

4.6 WATER SOLUBLE BAGS

Initial tests with empty water soluble bags and the paddle stirrer showed the horizontal paddles did not provide enough agitation. The paddle blade angle was adjusted by 20 degrees and sufficient agitation resulted. Empty water soluble bags dissolved in 1-2 minutes, although there was a problem with the bags wrapping around the stirrer drive shaft due to the bags floating on the surface of the water; this problem was reduced when the bags were placed below the stirring paddle blades. Tests showed that 3 litres of water was the minimum amount which can be stirred in the bottom of the 30 litre container without creating excessive vortexing.

4.6.1 Empty water soluble bags

During trials with empty bags, trial A, Table C.16, Appendix C, the water soluble bag disintegrated completely after 2.5 minutes of agitation and no deposits were found on the filter. When using 1 bag per 0.5 litre of water large lumps of bag occurred in the solution and caused wrapping of the stirring paddle. When the bag sank below the paddle blades (due to the assistance of a steel nut), the paddle wrap was considerably less, resulting in a better mix. The use of 1 bag per litre of water gave a better mix based upon a visual assessment. Figure 4.11, shows the time taken to fill five 0.5 litre containers was virtually the same irrespective of stirring time or the quantity of water used per bag.

4.6.2 Bags containing liquid pesticide (Oxytril)

Trial results using water soluble bags containing Oxytril, Trial B, can be found in Table C.17, Appendix C. When using 0.5 litre of water for each bag it was found to be insufficient to dissolve the bag even after stirring the solution for 5 minutes; large lumps occurred producing a visual assessment of 4 out of 5 and a filter deposit of 0.18 grams blocked the filter. When 2.0 litres of water per 2 bags was used there were less lumps, but the filter deposit (0.13 gms) was only slightly less than using 0.5 litre per bag. Unfortunately the filter blocked after 2.6 litres had flowed through it. When 3 litres of water were used to dissolve 3 bags there was very little filter deposit nor any lumps due to the extra quantity of water. Beaker fill times were longest when using the smaller quantities of water in the trials, see Figure 4.11. When larger quantities of water were used the flow rate increased considerably; this is also reflected in the results obtained in the DIN beaker tests. The results indicate the effect of pesticide viscosity; the beaker fill times were faster than the results obtained from using clear water in trial A.

4.6.3 Bags containing granular pesticide (EXP 4475)

Trial results using bags containing EXP 4475 (Ranger), Trial C, are shown in Table C.18, Appendix C. When 2 litres of water were used per bag, very good dispersal and mixing occurred, resulting in very little filter deposit. When 1 litre of water per bag was used a total disaster occurred because insufficient breakdown of the bags resulted in paddle wrap, high filter deposits and erratic flow rates into the beakers, see Figure 4.12. The viscosity of the pesticide solution affected both flow time into the collecting beakers and through the DIN measuring beaker. Problems occurred with the bags floating on the water surface and wrapping around the paddle stirrer; this was less of a problem when a greater quantity of water was used per bag. A conflict of modern technology exists, bags appear to be better suited to being placed into the very large quantities of water found in a conventional sprayer tank.

4.7 THE MILK TEST

Table 4.1, shows the results obtained in Tests 1-3.

4.7.1 First nozzle

The average time for the milk to appear at the first nozzle (nozzle number 6) was 12 seconds. At an average flow rate of 0.96 litres/minute, the water throughput was 11.5 litres.

11.5 litres was slightly higher than the figure already in the cab controller (specification 15.1 : 11.3 litres, Table B.2). The original specification was based on measuring the pipe length, outside diameters and the junctions. Figure B.10, Appendix B, shows the boom layout and pipe sizes.

4.7.2 Last nozzle

The average time for the milk to appear at the last nozzle (nozzle number 20) was 27 seconds. At an average flow rate of 0.96 litres/minute the water throughput was 25.99 litres; this was marginally smaller than 26.3 litres (the number entered as the pipe volume in the electronic controller, see Table B.1, Appendix B).

4.8 APPLICATION OF PESTICIDES TO CROPS

The response of weeds and diseased plants to the application of pesticides from the injection sprayer is the ultimate test of the effectiveness of the injection pump and the thoroughness of the mixing chamber. In conjunction with members of the Biology and Crops Department and Farms Director of the Royal Agricultural College, a number of field trials were conducted.

4.8.1 Application of herbicides to grass

2,4-D was applied to the grass weeds growing on the College sports fields at 2.8 l/ha in 200 l/ha of water. Using water, the sprayer was calibrated for the known area (4.5 ha) of the sports field. Daisies were the major weed problem.

The lower sports field was sprayed first and the area meter showed that the correct area had been covered (2 ha) but only 5.2 l of pesticide had been used, an under application of 0.6 litres over 2 ha. The Dose Cal Switch on the cab controller was adjusted (Appendix B) to 92% to correct this error. The pump had been calibrated with water and it is assumed that the increased viscosity of the concentrated herbicide resulted in the reduced application rate. The remaining 2.5 ha were then sprayed following the calibration correction and the area meter and the quantity of pesticide applied were correct.

Daisy plants began to die back to the satisfaction of the crop walker. The areas that had not received any pesticide continued to grow vigorously.

This small trial gave an indication that the injection sprayer will work satisfactorily provided the pump is calibrated to account for the pesticide viscosity by carrying out the calibration with pesticide. Once a calibration factor has been calculated for a particular pesticide at a known temperature, the same factor can be used repeatedly.

4.8.2 Application of herbicides to fodder beet

The weeds germinated very quickly after the crop was drilled and, possibly due to the wide row spacing, grew rapidly. The pesticides used and the application rates and dates are detailed below:

26th April chloridazon + ethofumesate (Spectron) at 3.0 l/ha
10th May metamitron (Goldtix WG) with an adjuvant at 1.7l/ha
17th May metamitron (Goldtix WG) at 1.7 kg/ha and
phenmedipham (Betanal E) at 2.5 l/ha
27th May ethofumesate (Nortron) at 1.5 l/ha
phenmedipham (Betanal E) at 2.5 l/ha

The blocks within the field were monitored. Table 4.2 shows

Table 4.2 __**Field trials with herbicides on Fodder Beet**__

Weed	days after treatment	plants per square metre injection	conventional
Pansy	0	25	20
(viola	14	75	66
arvensis)	19	28	53
	26	12	15
Black bindweed	0	0	0
(polygonum	14	20	5
convolvulus)	19	5	7
	26	2	8
Fumitory	0	15	15
(fumaria	14	10	40
officinalis)	19	3	6
	26	2	2

Table 4.3 **Field trials with fungicides on cereals**

TRIAL A
Barley - Gaulois Growth stage 49

	% mildew leaf cover		
leaf	sprayed	unsprayed	difference
leaf 3	0.63	0.78	0.15
leaf 4	1.57	1.63	0.06
mean	1.1	1.2	

TRIAL B
Barley - Gaulois Growth Stage 55
Flag leaf assessment

	% leaf area affected	
treatment	Rynchosporium	Brown rust
untreated	4.81	10.43
injection sprayer	0.52	0.61
conventional sprayer	0.45	0.57

TRIAL C
Slejpner winter wheat
Flag leaf assessment

treatment	% leaf area affected	
	Septoria	Brown rust
untreated	0.6	2.9
injection sprayer	0.4	1.5
conventional sprayer	0.3	1.4

the weed plants per square metre for the blocks treated with the conventional sprayer compared to the injection sprayer at the given intervals.

Analysis of variance on the weed populations 26 days after spraying, Table C.19, Appendix C, shows a significant difference between the conventional sprayer and the injection sprayer at the 95% and 99% values after spraying in the numbers of Pansy and Black bindweed. There was no significant difference between the injection sprayer and the conventional sprayer after treating Fumitory. The trial results, Table 4.2, indicate the injection system could control the weeds at least as well as a conventional sprayer.

The ability of the injection system to pump and mix pesticides of differing viscosities was noted e.g. the quantities used in relation to the target application rate. The water soluble granules of metamitron (Goldtix) were first carefully stirred into water in the 30 litre container using an electric paddle stirrer, 1 kg of Goldtix being added to 4 litres of water. As the granules are normally added to a much greater volume of water in a conventional sprayer tank there are no guidelines on a suitable mix for the injection sprayer, and the 1 kg to 4 l was an arbitrary choice for convenience. This produced a mix with the consistency of watery porridge and the pump Dose Cal function (Appendix B) was set to 85%.

The weed control was acceptably uniform and was considered satisfactory by the crop walker, although there was an area at one of the headlands where weeds were not controlled. There is a simple explanation for this observation; as the sprayer moves off along the field at the start of the spraying operation, it takes a certain time for the pesticide to move through the boom pipes to the nozzles, resulting in an area of unsprayed land. The injection system controlled weeds to the same degree as a conventional sprayer.

4.8.3 Application of fungicides to cereals

Three trials were held on two cereal crops, winter barley and winter wheat. The trials compared the effectiveness of the injection system against unsprayed areas or a conventional sprayer.

The results are shown in Table 4.3 and are taken 4 days after the application of fungicides.

Trial A

Gaulois winter barley was sprayed at growth stage 49 to control mildew (*Erysiphe graminis*) with fenpropimorph (Corbel) at 0.5 l/ha and propiconazole (Tilt 250 EC)at 0.25 l/ha in 100l/ha of water.

Tables 4.3 and C.20, Appendix C, show that there was very little difference between the sprayed and unsprayed blocks of the field. Analysis of variance shows no significant difference on leaf 3 or leaf 4 between the unsprayed and sprayed plots. The incidence of mildew was slight.

Trial B

The larger field of Gaulois was sprayed at growth stage 55 when *Rynchosporium* and brown rust (*Puccinia spp.*) were noted with propiconazole + tridemorph (Tilt turbo 475 EC) at 1 l/ha in 200 l/ha of water.

Tables 4.3 and C.20 Appendix C, show the results. Both the conventional sprayer and the injection sprayer gave a good level of control of the diseases. The conventional sprayer gave significantly better control than the injection sprayer at the 99% level.

Trial C

A large field of Slejpner winter wheat was treated with propiconazole (Tilt 250 EC) at 0.5l/ha in 100l/ha of water.

The level of *Septoria* was low so the trial was disappointing, Table 4.3. The level of Brown rust was higher and the injection sprayer gave comparable results to the conventional sprayer; analysis showed no significant difference between the injection sprayer and the conventional sprayer. There was a significant difference between the treated and untreated areas.

4.9 SPOT TREATMENT OF WEEDS

The observations in the laboratory trials regarding the time taken for the tracer to reach the first and last nozzles, along with the validation of the flow rate calculations in section 4.8, resulted in this trial.

The injection sprayer applied paraquat to a grass field at varying application rates. Trial plots were measured and the results recorded 48 hours after spraying.

Figure B.10, Appendix B, shows the boom pipe layout and nozzle designation. Nozzles Numbers 6 and 7 are the first nozzles; nozzle No.20 is the last. Figure 4.13 shows the effect of paraquat on the sward at an application rate of 100 l/ha and 200 l/ha from the right hand boom. The boom and nozzle configuration is also indicated.

Figure 4.14 shows the effects of the 20 metre boom on the sward at an application rate of 200 l/ha. Plates 4.3 and 4.4 show the field trials.

4.9.1 Trial A

At 100 l/ha the paraquat appeared at the first nozzles (Nos. 6 and 7), at 61 metres (25.24 seconds) and the last nozzle at 144 metres (59.58 seconds). The pesticide was switched off after 150 metres and the distance taken for the pesticide to be flushed through the system was noted. The first nozzles (6 and 7), cleared after 62.5 metres and the last nozzles at 147 metres.

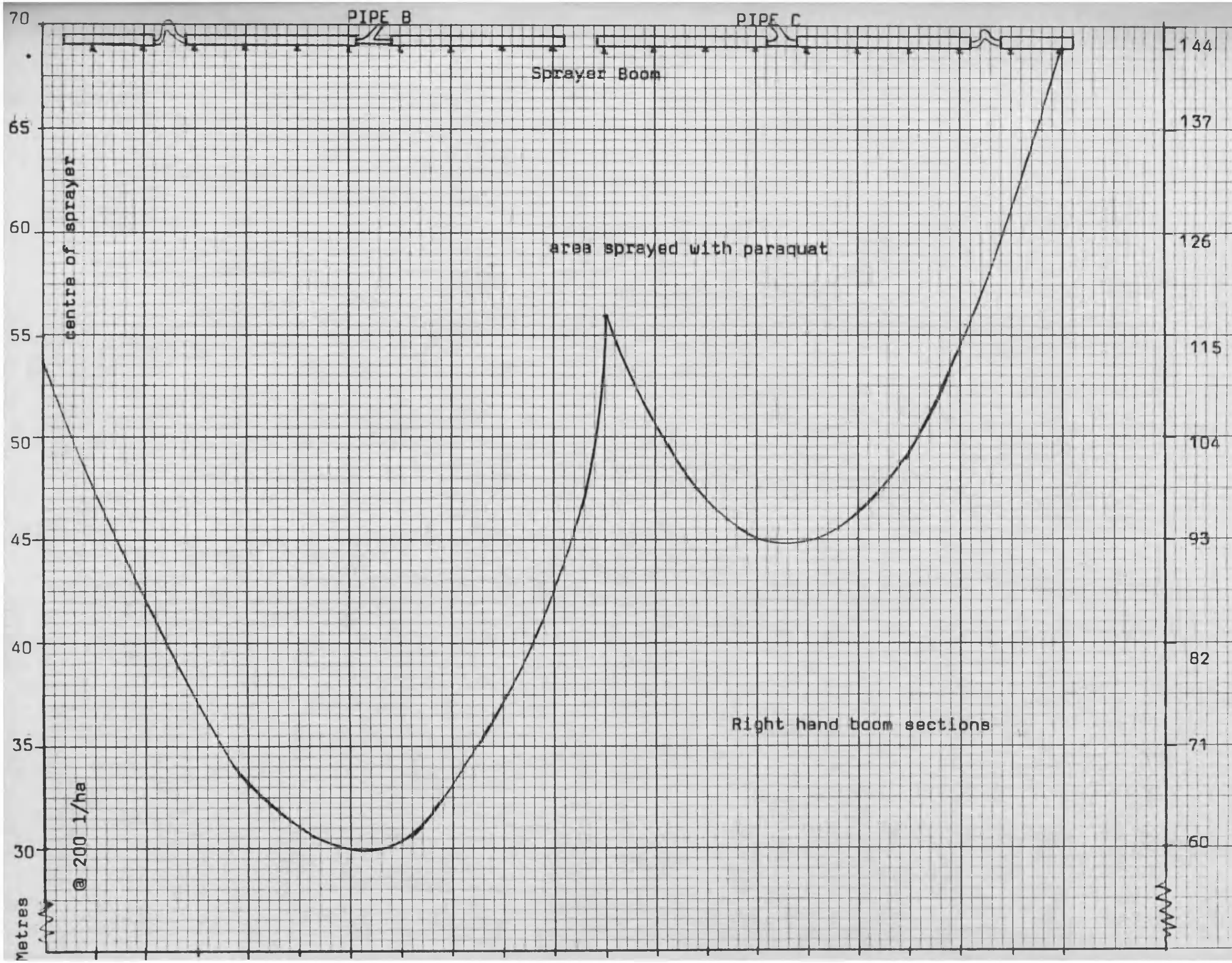


Figure 4.13

System response profile: right-hand boom: 100 l/ha and 200 l/ha

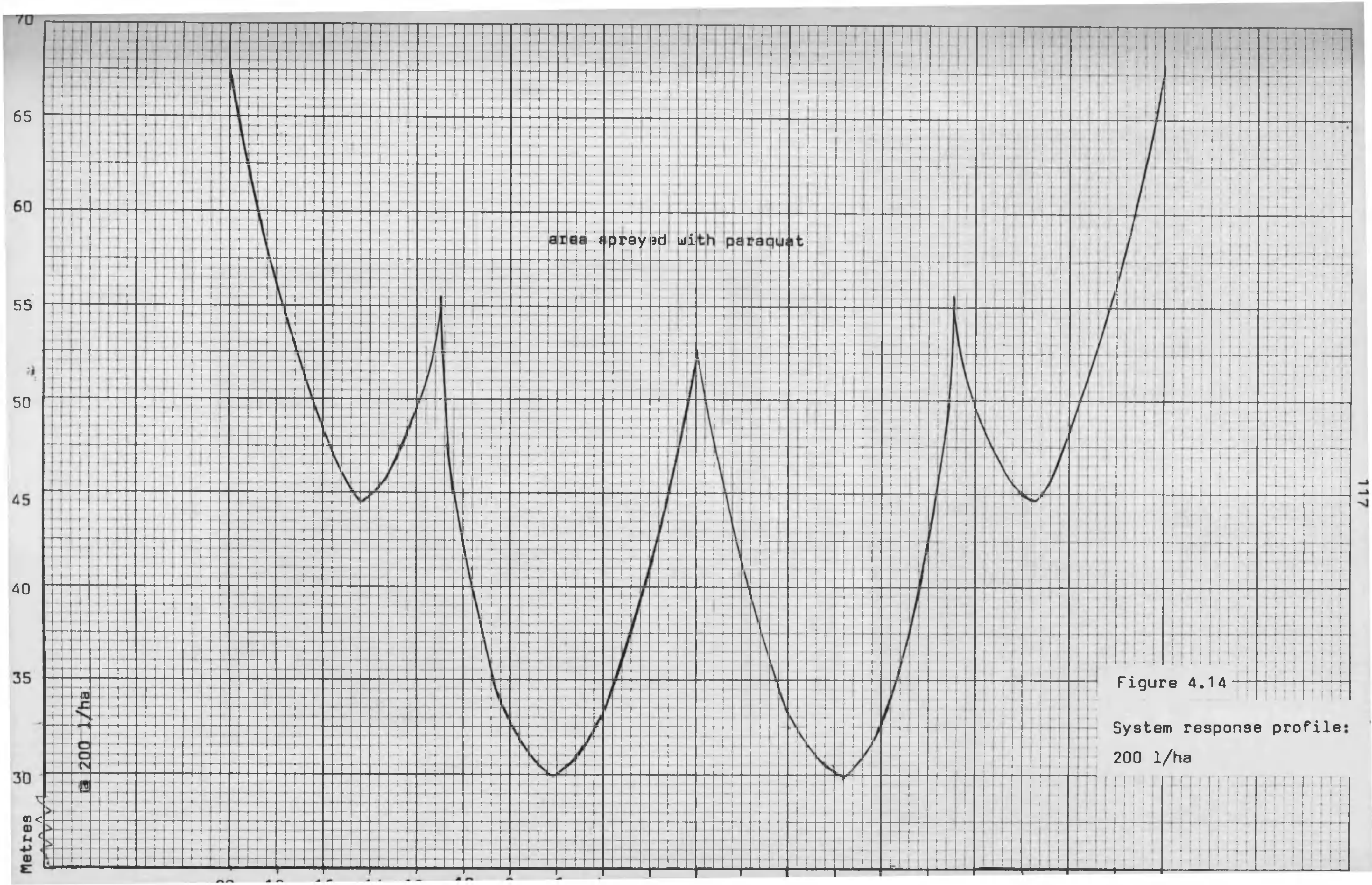


Figure 4.14

System response profile: 200 l/ha

PLATE 4.3 Field trials using paraquat on grass showing the time delay for pesticide to flow through the booms

PLATE 4.4 Field trials using paraquat on grass

Table 4.4 Comparison of the results from the laboratory and field trials

APPLICATION RATE: 100 LITRES PER HECTARE AT 8.7.km/h

Time taken (seconds) for the pesticide to reach:	Flow rate calc. 100 l/ha	Potassium permanganate	Field Test
first nozzle	23.76	25.0	25.24
last nozzle		55.0	59.58

APPLICATION RATE: 200 LITRES PER HECTARE AT 8.7 km/h

Time taken (seconds) for the pesticide to reach:	Flow rate calc. 200 l/ha	Milk Test	Field Test
first nozzle (seconds)	11.88	12.0	12.41
last nozzle (seconds)		27.0	28.55

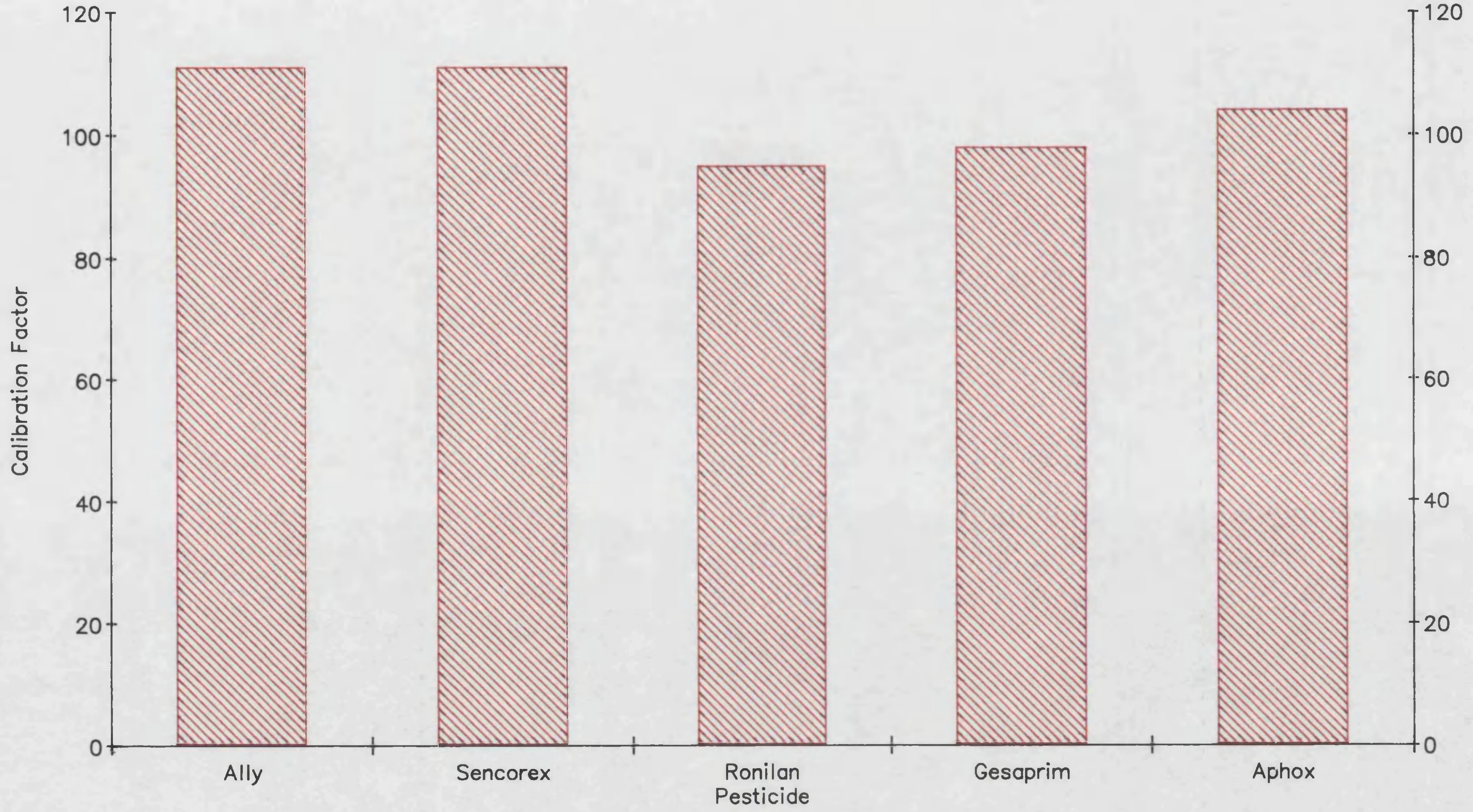
4.9.2 Trial B

At 200 l/ha the paraquat appeared at the first nozzle (Nos.6 and 7) at 30 metres (12.41 seconds) and the last nozzle at 69 metres (28.55 seconds).

Table 4.4 compares the field test results with those obtained using potassium permanganate, milk and the mathematical analysis. The time taken for paraquat to reach the first nozzle is very similar in all the tests. The time taken for paraquat to reach the last nozzle is slightly longer (at 100 l/ha: 8% and 200 l/ha: 5.7%) than the other tests. The reason for this delay may be due to tractor wheel slip, particularly as there is a lower variation of 5.7% with the faster response time at the higher application rate 200 l/ha, compared with the slower response at 100 l/ha.

Fig.4.15 PESTICIDE & PUMP CALIBRATION

Powders at Weasenham Farm Trials



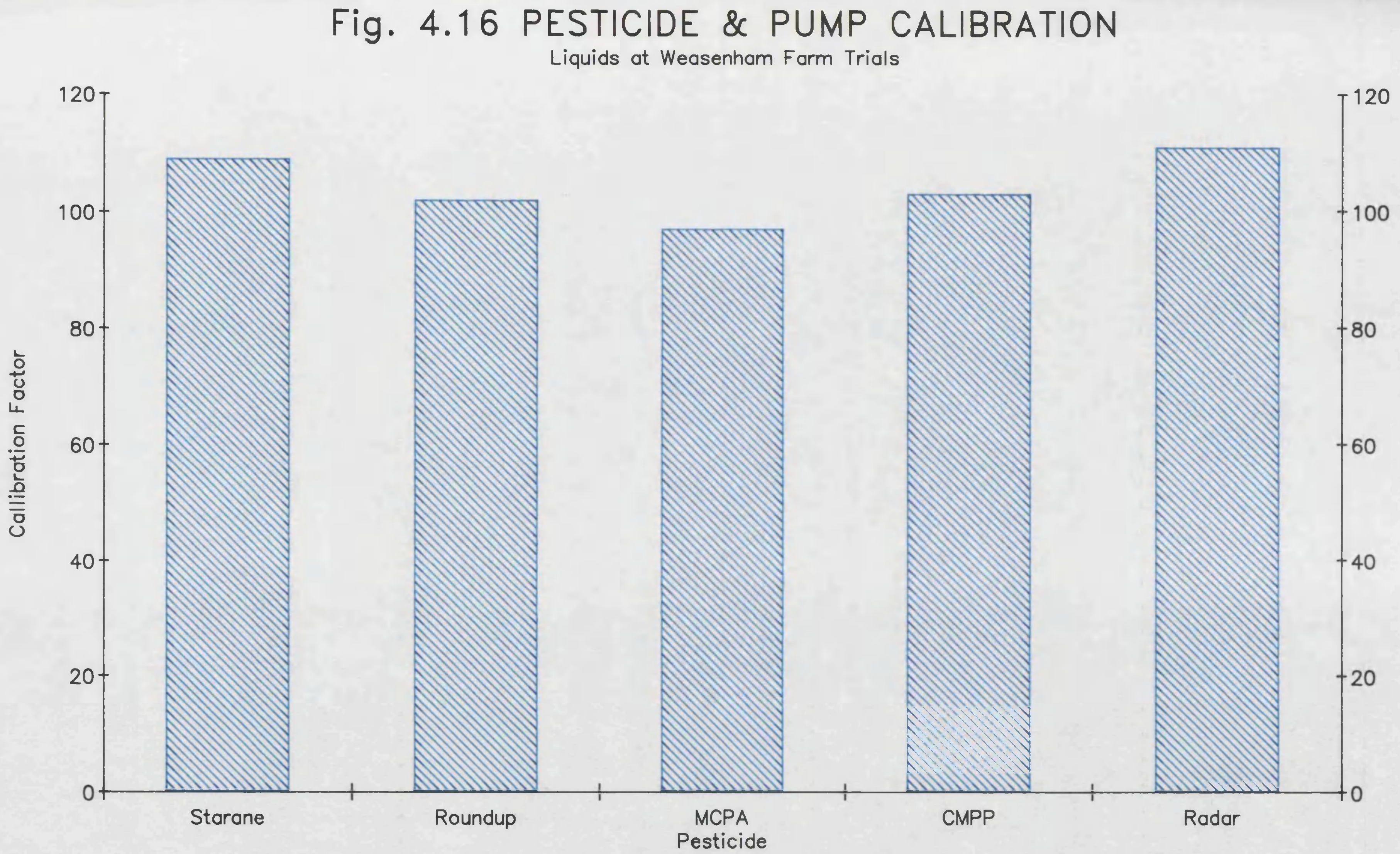


Fig. 4.16 PESTICIDE & PUMP CALIBRATION
Liquids at Weasenham Farm Trials
Calibration Factor
Starane
Roundup
MCPA
CMPP
Radar
Pesticide
0
20
40
60
80
100
120

4.10 OBSERVATIONS ON THE LARGE-SCALE FIELD TRIALS

The field trials carried out so far needed to be developed to see if the injection sprayer would operate so well under commercial farming conditions. Information was obtained via work records/field records and interviews with the staff involved.

4.10.1 Pesticides used

Tables C.21 and C.22, Appendix C, show the products used, the crop, the injection application rates, the dilution rates and the calibration factor.

The injection sprayer was used on 3200 hectares of crops on Weasenham Farms, ranging from cereals and potatoes to sugar beet and fodder beet. The injection application rates varied from 30 grams in 1 litre of water with metsulfuron - methyl (Ally) to 4 litres mecoprop (CMPP) per hectare.

The dilution rates varied from 110 to 400 l/ha. The calibration factor (%), reflecting differing pesticide viscosities, varied from 95 to 116, Figures 4.15 and 4.16.

The sprayer and injection system performed satisfactorily as far as the application of the product and its effect were concerned. There were no problems regarding the efficiency of the system in carrying out the task of weed or pest control.

4.10.2 The Weasenham Farm Manager's comments

a) accuracy

The injection sprayer was very accurate; it applied all the products at the dose level set on the in-cab monitor. The sprayer operator calibrated each product and set the required calibration factor on the controller, Tables C.21 and C.22, Appendix C. The field results were satisfactory and comparable to a conventional crop sprayer.

b) advantages

The following advantages were given in order of priority:

i) there is no need to dispose of surplus pesticide when rained off, the part-used containers can be returned to the store thus saving money and overcoming the problems of environmental pollution.

ii) there is no need to dispose of sprayer tank washings, thus reducing operator contamination leading to

iii) time saved between spraying as the operator can wash the system through in the field rather than having to return to the main yard. This is particularly important when spraying between different crops e.g. sugar beet is very susceptible to some cereal pesticides and normally would require very thorough washing out, taking upwards of one hour.

iv) more hectares per day can be sprayed due to not having to mix/calibrate the required amounts at the beginning of spraying and not having to spend so much time washing out the system at the end of the day.

v) handling the concentrated pesticide is safer, due to the filling station being used to fill the 35 litre containers from the manufacturer's original containers.

vi) more accurate use and less wastage of pesticides i.e. what is not used is still in the container and not mixed in the tank. Under normal spraying operations there is always a certain amount of pesticide left in the bottom of the tank, in the hoses and in the booms. This is usually washed out.

vii) spot treatment may be of use in the future but was not carried out during the field trials.

c) <u>maintenance requirements</u>

The maintenance requirement was very low as the injection pumps did not require maintenance.

d) <u>function errors</u>

i) the injection sensors gave rise to a lot of problems, particularly when the container was becoming empty. Certain pesticides are cloudy and the operator cannot tell if pesticides are being metered, resulting in an area being unsprayed. In most cases the operator travelled back over the field and re-sprayed the area. On the potato crop an area was missed and this resulted in about 2 days longer to harvest the crop due to weeds.

ii) the pipes from the container to the injection pump were affected by certain pesticides, in particular the solvent in phenmedipham (Betanal E), causing the pipes to soften.

e) reliability of service

The injection system proved to be very reliable once the aforementioned problems had been resolved.

f) experience of the operator

There are three sprayer operators at Weasenham Farms but only one was considered suitable to obtain the best from the system. It is felt that a very able operator is required to understand the system thoroughly.

4.10.3 The Weasenham Farms sprayer operator's comments

There were three major advantages associated with the direct injection sprayer.

i) eliminating the need to rinse the sprayer tank resulted in a great deal of time being saved, both between crops and at the end of the day.

ii) the dangers of personal contamination associated with pesticide container handling and decanting had been reduced due to the use of large pesticide containers in conjunction with the filling station.

iii) once a pesticide had been calibrated for the system, using the calibrating vessel, it was easy to set the

Table 4.5 Workrate spreadsheet: Kemble Estate

WORKRATE- A spreadsheet to compare farm machinery outputs
A.J.Landers, Royal Agricultural College, Cirencester, Glos.

Trial Farm: Kemble Estate, Kemble, Cirencester, Glos.

INPUT DATA	MODEL A	MODEL B
Implement width (m)	24	24
Capacity (kg or litres)	1800	1800
Forward speed (km/h)	10	10
Application rate (kg/ha or l/ha)	240	240
Transport time (min)	6	6
Filling time (min)	17	12
Field efficiency (%)	65	65

OUTPUT	MODEL A	MODEL B
Area covered per load (ha)	7.5	7.5
Filling rate (kg/min or l/min)	105.9	150.0
Spot workrate (ha/h)	24.0	24.0
Total time per load (min)	57.8	52.8
Overall workrate (ha/h)	7.8	8.5
Overall efficiency (%)	32.4	35.5
COMPONENTS		
Application time per load (min)	28.8	28.8
Application time (%)	49.9	54.6
Filling time per load (min)	17.0	12.0
Filling time (%)	29.4	22.7
Transport time per load (min)	12.0	12.0
Transport time (%)	20.7	22.7

Table 4.6 Workrate spreadsheet: Weasenham Farms

WORKRATE- A spreadsheet to compare farm machinery outputs
A.J.Landers, Royal Agricultural College, Cirencester, Glos.

Trial Farm: Weasenham Farms, Feltwell Fen, Norfolk

INPUT DATA	MODEL A	MODEL B
Implement width (m)	24	24
Capacity (kg or litres)	2000	2000
Forward speed (km/h)	10	10
Application rate (kg/ha or l/ha)	200	200
Transport time (min)	2	2
Filling time (min)	15	10
Field efficiency (%)	65	65

OUTPUT	MODEL A	MODEL B
Area covered per load (ha)	10.0	10.0
Filling rate (kg/min or l/min)	133.3	200.0
Spot workrate (ha/h)	24.0	24.0
Total time per load (min)	57.5	52.5
Overall workrate (ha/h)	10.4	11.4
Overall efficiency (%)	43.5	47.7
COMPONENTS		
Application time per load (min)	38.5	38.5
Application time (%)	66.9	73.3
Filling time per load (min)	15.0	10.0
Filling time (%)	26.1	19.1
Transport time per load (min)	4.0	4.0
Transport time (%)	7.0	7.6

Table 4.7 Workrate spreadsheet: Stowell Park

WORKRATE- A spreadsheet to compare farm machinery outputs
A.J.Landers, Royal Agricultural College, Cirencester, Glos.

Trial Farm: Stowell Park, Northleach, Glos.

INPUT DATA	MODEL A	MODEL B
Implement width (m)	24	24
Capacity (kg or litres)	2100	2100
Forward speed (km/h)	10	10
Application rate (kg/ha or l/ha)	90	90
Transport time (min)	10	10
Filling time (min)	15	10
Field efficiency (%)	65	65

OUTPUT	MODEL A	MODEL B
Area covered per load (ha)	23.3	23.3
Filling rate (kg/min or l/min)	140.0	210.0
Spot workrate (ha/h)	24.0	24.0
Total time per load (min)	124.7	119.7
Overall workrate (ha/h)	11.2	11.7
Overall efficiency (%)	46.8	48.7
COMPONENTS		
Application time per load (min)	89.7	89.7
Application time (%)	71.9	74.9
Filling time per load (min)	15.0	10.0
Filling time (%)	12.0	8.4
Transport time per load (min)	20.0	20.0
Transport time (%)	16.0	16.7

Table 4.8 Pesticide residues in crop sprayers

MANUFACTURER	MODEL	TANK CAPACITY (l)	BOOM WIDTH (m)	QUANTITY REMAINING (l)
CHAFER	T2000 trailed	2000	24	83.3
HARDI	TZ1500 "	1500	18	40.5
ALLMAN	625 mounted	625	12	13.5

required dose level on the controller. Once a calibration factor number was obtained for a product it could be used time after time with the same results.

4.11 IMPROVING SPRAYING LOGISTICS

Model A: conventional sprayer Model B: injection sprayer

Kemble Estate use an MB trac and Hoegen-Dikof demountable sprayer. The tractor was purchased for a high road speed as filling occurs at the farmyard. Table 4.5 shows the results. The overall workrate, Model B, improved by 9% (0.7 ha/h) and the overall efficiency by 3.5%. The sprayer spent 5% more time actually spraying.

Weasenham Farms use a trailed Chafer sprayer and a water bowser in the field. Table 4.6 shows the results. The overall workrate, Model B, has increased by 1 ha/h and the overall efficiency by 4%. Time spent applying pesticides has increased by 7%. The effect of the faster turn around with container connection rather than decanting is shown most clearly at Weasenham Farms because more time is spent spraying due to the use of a bowser.

Stowell Park use an MB trac and a Cleanacres Airtec sprayer, averaging 90 l/ha. The sprayer returns to the farm yard to refill with water. Table 4.7 shows the workrate, Model B, has improved by 0.5 ha/h and the overall efficiency by 2%. The very low application rate means the sprayer is in work for much longer and so filling time does not have such a marked effect.

4.12 PESTICIDE RESIDUES IN CONVENTIONAL SPRAYERS

Table 4.8 shows the quantities remaining in three sprayers of varying specifications. The Chafer sprayer has large bore pipes, necessary for applying large quantities of liquid fertilizer per hectare, but is also used for applying pesticides. The centrifugal pump on the Chafer holds much more liquid than a diaphragm pump. A farmer applying pesticides at 100 l/ha would lose an accurate spray pattern with 83 litres remaining in the 'system'. The Allman mounted sprayer has a smaller tank base coupled with shorter lengths of pipe of smaller diameter than the Chafer.

4.13 CALCULATION OF FLOW RATES

a) Time to spray 1 ha:

1 ha = 10,000m^2

20m boom, therefore travel 500m to spray 1 ha

Speed: 8.7 km/h = 8700m/h

$$t = \frac{500\text{m}}{8700\text{m/h}}$$

= 0.0575 h/ha

= 3.42 mins/ha

Time to spray 1 ha = 3.42 mins.

b) Pesticide flow rate/min:

$$\frac{\text{dose}}{\text{mins}} = \frac{2.5 \text{ litres}}{3.42 \text{ mins}}$$

= 0.73 l/min of pesticide

= 43.86 l/h of pesticide

Pesticide flow rate: 0.73 l/min

c) Time for the pesticide to flow from the container to the mixing chamber:

Volume of the pesticide pipe from the container to the mixing chamber (machine spec. 6.2) = 0.250 l

Flow rate = 0.73 l/min

$$= \frac{0.25}{0.73}$$

= 0.34 mins (17.5 seconds)

Time for the pesticide to flow from the container to the mixing chamber = 17.5 seconds

4.13.1 Flow rate calculations - spraying at 100 l/ha

a) Sprayer flow rate:

Volume of sprayer pipe to the first nozzle (machine spec. 15.1) = 11.6 l.

application rate: 100 l/ha

3.42 mins to drive 1 ha

$$= \frac{100}{3.42}$$

= 29.24 l/min

sprayer flow rate = 29.24 l/min

b) Time for pesticide to flow from the mixing chamber to the first nozzle:

sprayer pipe capacity to first nozzle: 11.6 l

$$= \frac{11.6 \text{ l}}{29.24 \text{ l/min}}$$

= 0.39 min

= 24 secs

time for pesticide to flow from the mixing chamber to the first nozzle = 24 secs

c) Distance travelled before pesticide appears at the first nozzle:

forward speed: 8.7 km/h = 2.42 m/sec

24 secs x 2.42 = 58.08 metres

distance travelled before pesticide appears at the first nozzle = 58.08 metres

d) Time for the pesticide to travel from the container to the first nozzle and distance travelled during that time:

distance travelled from the time the pesticide is injected at the mixing chamber to the first nozzle = 58.08m

time for pesticide to reach the mixing chamber=17.5 secs

time from the mixing chamber to the first nozzle = 24.0secs

total time for the pesticide to travel from the container valve to the first nozzle = 41.50 secs

forward speed = 8.7 km/h = 2.42 m/sec

41.50 x 2.42 = 100.43 metres

distance travelled from the time the container valve is switched on until the pesticide arrives at the first nozzle = 100.43 metres.

4.13.2 Flow rate calculations - spraying at 200 l/ha

a) Sprayer flow rate:

Volume of sprayer pipe to the first nozzle (machine spec. 15.1) = 11.6 l.

application rate: 200 l/ha

3.42 mins to drive 1 ha

$$= \frac{200}{3.42}$$

= 58.48 l/min

sprayer flow rate = 58.48 l/min

b) Time for pesticide to flow from the mixing chamber to the first nozzle:

sprayer pipe capacity to first nozzle: 11.6 l

$$= \frac{11.6 \text{ l}}{58.48 \text{ l/min}}$$

= 0.198 min

= 12 secs

time for pesticide to flow from the mixing chamber to the first nozzle = 12 secs

c) Distance travelled before pesticide appears at the first nozzle:

forward speed: 8.7 km/h = 2.42 m/sec

12secs x 2.42

= 29.04 metres

distance travelled from the time the pesticide is injected at the mixing chamber to the first nozzle = 29.04 metres

d) Time for the pesticide to travel from the container to the first nozzle and distance travelled during that time:

time from the container to the mixing chamber = 17.5 secs and time from the mixing chamber to the first nozzle = 12.0 secs

Total time for the pesticide to travel from the container valve to the first nozzle = 29.50 secs

forward speed = 8.7 km/h = 2.42 m/sec

29.50 x 2.42 = 71.39 metres

distance travelled from the time the container valve is switched on until the pesticide arrives at the first nozzle = 71.39 metres.

CHAPTER 5. DISCUSSION OF LABORATORY AND FIELD TRIALS

The equipment used in the first test (Test 1 and 2) was found to be unable to cope with increased output settings on the pump because belt slip caused a reduction in the expected output increase. When a hydraulic motor was substituted for the belt and pulley arrangement the output was found to be linear at all settings.
The two standard pump heads (pumps A and B) showed very similar outputs, but at low dose rates the smaller pump head was used to achieve greater accuracy. The Wallace and Tiernan piston pump, when positively driven, was found to be accurate giving consistent results in all the tests.
A coefficient of variation of approximately 2% occurs at the shorter stroke length of 2.5 l/ha (section 4.3.6 excepted), irrespective of speed, and a coefficient of variation of 0.04% approximately at the longer stroke length of 5.0 l/ha. This is extremely low, reflecting the low dispersion of values obtained in the trials and demonstrating the accuracy of this type of pump.

When liquids are pumped, the output of the pump will be dictated by the viscosity of the fluid which in turn is influenced by the temperature and pressure. Way et al (1989) found large variations in peristaltic pump output with various pesticides at different temperatures. Laboratory trials with the Tiernan pump using glyphosate and isoproturon showed only very small variations in pump output when the temperature was varied, but the viscosity of some pesticide formulations at different temperatures may require the pump to be calibrated specifically for them. Once a calibration number had been established, its repeatability was excellent.

The injection pump responded quickly to changes in forward speed and dose level adjustments. When the dose level was adjusted by 25% from 5.0l/ha to 3.75 l/ha and then a further 25% to 2.50 l/ha it took about 20 seconds before a response was detected at the first nozzle on the boom. The pump output was consistent at each of the preset dose rates. Low coefficients of variation and standard deviation were obtained at all dose levels, indicating that both injection pump and electronic controller were accurate. A system that allows the dose rate to be increased or decreased accurately to known values while spraying could be of great practical value.

Boom flow characteristics were measured in the laboratory and the field. Pesticide concentration levels between nozzles were consistent and remained consistent over a period of time when the injection pump injected pesticide at a constant rate. The mixing chamber appeared to mix the pesticide and water very well as there were no signs of streaking in any of the trials. This was supported by the field trial evidence on weed control and fungicide activity.

Switching the water flow on and off whilst turning at field headlands may, however, result in over/under application of pesticide, especially at very high dose levels. Potassium permanganate was used as a pesticide mimic in these trials and the results suggest that it was an entirely satisfactory tracer for this purpose.

The time that pesticides would take to reach the first and last nozzles on the boom was monitored in the laboratory. Tests showed that it took between 25 and 30 seconds before the full concentration was attained at the first nozzle but 30-40 seconds longer for the tracer to reach the last nozzle due to the larger pipe volume between the point of injection and the last nozzle. Spraying a field at 8.7 km/h would result in driving 60.5m before the desired concentration level reached the first nozzle and 133m before it reached the last nozzle. This delay is obviously too great for accurate and practicable spot treatment; the operator would have to be made aware of where the patch of weeds requiring treatment was situated long before reaching them.

The time delay measured in these tests was directly related to the volume of pipework between the point of injection and the nozzle (which was 11.6 litres on the Hardi sprayer used) and to the volume rate of application. Reducing this volume, by placing the injection point and mixing chamber nearer the nozzles or injecting at individual nozzles would reduce the response time. Injecting at individual nozzles, as described by Larson et al (1982) and Tompkins and Howard (1988), would result in a more complex sprayer with pipes conveying concentrated pesticide to each nozzle on the boom. Alternatvely, injecting pesticide into each sprayer boom section would result in a longer delay due to the lower flow rates. Increasing the application rate from 100 to 200 l/ha halves the response time, but the advantages of spraying at the lower volumesare then lost. The volume of pipework between the mixing chamber and the nozzles can also be reduced to some extent by using small bore pipes but the scope is limited by increased friction.

Trials were carried out to compare the time delays found in the laboratory with field results. As predicted the delay was approximately halved when paraquat was applied at 200 l/ha compared with 100 l/ha; however, probably because of tractor wheelslip on the very dry grass, the distance travelled before paraquat reached the nozzles at the 200 l/ha rate was not exactly halved. The dry grass with long dry stalks made precise observations of the cut-off line or boundary between desiccated sward and green grass difficult. The fields were exceptionally dry following two dry summers on the Cotswolds. The lack of precision of the boundary was further increased by the choice of paraquat, which often works effectively at dose levels much below those normally recommended. Lush green winter cereal desiccated with paraquat in the Spring would have produced sharper boundaries.

The distance travelled after switching off the pesticide at the injector and before a 'no effect' was recorded, was slightly longer than the distance travelled after switching on again and before the pesticide appeared at the nozzles. The reason for this extra distance could be due to a delay in removing all traces of paraquat from the boom pipes. Depending on the viscosity or cohesiveness of the product used, the distance travelled or time delay will vary according to the effectiveness of the pesticide flushing process. To summarise, both shorter (and smaller bore) pipes downstream of the mixing chamber and higher volume rates lead to faster reaction times. When a changed application depends on physical action by the operator, the delays, especially that of pesticide reaching the furthermost nozzle on the boom, would make the system difficult to operate.

The treatment of weed patches or isolated diseased areas rather than spraying the entire field, has great potential for a reduction in pesticide use; this may result in financial savings for the farmer and will reduce the pesticide load on the environment. Several methods of identifying patches of weeds and disease, such as satellite imagery, aerial photography, 'in the row' identification and vehicle location systems are under review, section 5.4. As Baines (1991) stated "Advanced technology must be used to help farmers and growers develop techniques to protect the environment and direct injection spraying appears to be a good example."

Physically measuring the volume of the pipework system downstream from the mixing chamber was time consuming, so alternative methods were considered. The results showed that using milk as a tracer was a workable and much simpler procedure. The results obtained in the milk test proved to be comparable to those from measuring pipe volumes. With large sprayers the pipe runs can be complex and therefore difficult to measure and the milk test would be a simpler and quicker method. Milk is safe to handle, readily available and easy to observe as it leaves the nozzle. Unfortunately it has a high Biological Oxygen Demand (BOD:140,000mg/litre) and is a notorious pollutant of water-courses. Milk should therefore be well diluted before it enters the soil and the milk test carried out well away from all watercourses. Food colouring could also be used as a flow detector; it is readily available, inexpensive and non-staining.

When a spraying task is completed with a conventional sprayer, some pesticide will be left in the 'system' of pump, pipes and valves. The test using the Chafer sprayer showed that 83 litres of liquid remained in the sprayer after the spray pattern disintegrated due to the entrainment of air into the liquid; depending on the unit cost, dose and volume rate of pesticides being applied, the loss of 0.83 ha worth of pesticide could be relatively expensive; this loss would occur repeatedly during the spraying season. In addition to the monetary value of the pesticide remaining in the system, there is the added cost of thorough rinsing out, especially of herbicides, and of the safe disposal of the rinsate. If the spraying operation is interrupted or has to be delayed for any reason, such as rainfall, an operator using an injection system can return the concentrate pesticide container to the store. Conventional sprayers must keep the tank contents constantly agitated to prevent stratification, so delay in this case can be expensive, particularly if rainfall is prolonged.

When an injection sprayer has finished spraying the operator is able to switch from pesticide to a flushing solution to purge the mixing chamber and pipelines of pesticide. The time taken to purge the system will depend on the pesticide viscosity or cohesiveness and the flushing medium. The system can be purged satisfactorily with water but trials with 'Supray Spraynett', a proprietary sprayer tank cleaner, indicate a 38% reduction in the quantity required to flush Isoproturon (Hytane) from the injection system. A good purging system should reduce the risk of operator contact with pesticides as the danger of splashes whilst cleaning a conventional sprayer (especially its tank) is much reduced.

The use of water soluble bags containing pesticide is claimed to reduce operator contamination when filling a sprayer. Trials with water soluble bags showed that 2.5 minutes is the minimum time needed to fully dissolve the bag. The best dispersal of soluble bags occurred when the largest amount of water was used. Bags containing Oxytril (a formulation of bromoxynil and ioxynil) needed a minimum of 3 litres of water to dissolve 3 bags; when the volume of water was reduced the filters blocked. However, bags containing Ranger needed only a minimum of 2 litres per bag. The 30 litre container needs a minimum of 3 litres of water to reduce vortexing problems and the paddles need slight adjustment to ensure effective mixing of water soluble bags. Ranger bags floated on the surface of the water and thus created a problem by wrapping themselves around the paddle drive shaft, and failing to disperse completely even after 5 minutes of stirring. Sufficient agitation is required to ensure complete dispersion of the bags and wrapping around the stirring paddle must be prevented.

Field trials using fungicides and herbicides on a variety of crops confirmed the accuracy found in the laboratory studies provided that the pump had been calibrated with the pesticide before use. The Dose Cal. figure for the cab controller varied by 16% when using different liquid pesticides, showing the need to calibrate the pump for each pesticide. The level of weed and disease control was as expected, comparable to that achieved by a conventional sprayer. The injection sprayer appeared to mix the pesticide and water adequately as there were no signs of streaking in any of the trials. However, the major problem of delay in pesticide reaching the first and last nozzle remained. A change in driving technique is required with the present equipment, particularly when the operator has finished the field as he needs to return to the start of the field to spray out the pipelines so as to 'infill' the untreated area.

The large-scale field trials at Weasenham Farms rapidly proved the reliability of the injection sprayer. The variety of crops, from field vegetables through to cereals and sugar beet, at various dose rates gave a good test for pump accuracy. The level of weed and disease control was comparable to that achieved with a conventional sprayer. The faults that occurred were soon rectified, for example, the pipe from the pesticide container to mixing chamber was affected when Betanal E (a formulation of phenmedipham containing xylene) was used. The solvent xylene in Betanal E weakened the polypropylene pipes confirming the views expressed by Amsden and Southcombe (1977). The advantage of greater timeliness achieved by not having to wash out the tank proved to be important for two reasons. Firstly, changing over from one crop to another occurred frequently on this large mixed cropping farm, and secondly, a faster turn around was achieved when connecting pesticide containers rather than decanting traditional 5-10 litre packs. On the South Downs there are only about 145 days that are suitable for spraying residual pesticides according to research by Spackman (1983), and it is suggested that injection sprayers can improve timeliness by eliminating tank washing time and reducing the time spent on calculating pesticide quantities and loading pesticide containers.

The electronic controller presented no problems to the operator at Weasenham Farms and most of the mechanical problems that arose were easily solved on the spot.
On the injection sprayer used in these trials all the working parts were of high quality and worked well with only minor problems and showed little signs of wear. The machine generally gave accurate, reproducable results which previuos work has shown to be essential if injection sprayers are to be generally adopted (Reichard and Ladd (1983); Schmidt (1983); and Budwig et al (1988).

Table 6.1 <u>Examples of pesticide rate changes according to soil type</u>

Product Trade name chemical name	Crop	Application Rate /ha light soil	 med-heavy soil
Albrass propachlor	Brassicas Leeks Onions	9.0l	>O.M.13.0l
Gesatop500FW simazine	Maize Beans	2.3l 1.7l	3.4l 2.3l
Nortron & ethofumesate Venzar lenacil	Sugar Beet	5.0l 0.5l	10.0l 1.0l
Opogard 500FW terbutryne & terbuthylazine	Peas Beans Potatoes	1.6l 2.3l	3.4l > O.M 3.4l
Pyramin chloridazon	Sugar Beet	1.7kg	5 kg

Table 6.2 <u>Major pesticides used at the Royal Agricultural College Farms - 1988-89</u>

Product	Quantity Used litres	Container Size litres
CMPP 60% mecoprop	132	20
Corbel fenpropimorph	113	5 or 1
Grammoxone paraquat	97	5
Headland dual carbendazim + maneb	155	5
Hytane 500 FW isoproturon	270	5 or 10
Javelin diflufenican + isoproturon	525	5

CHAPTER 6. GENERAL DISCUSSION

6.1 REDUCING PESTICIDE USE

When using a conventional crop sprayer the operator applies pesticide to the whole field at a constant application rate, the operator is unable to alter the application rate to accomodate varying levels of weed or disease infestation and cannot change the mix of pesticide as the problems vary across the field. The use of an injection system, in conjunction with an in-cab electronic controller, would remove these limitations. The operator can switch from up to three injection pumps, each pump connected to a separate pesticide container; any combination of pumps may be used, resulting in an on-the-move alteration of the products and their rates being applied e.g. a pesticide for broad-leaf weeds could be applied across the whole of a cereal field using pump 1 and pesticide from container A and as the sprayer approaches a patch of wild oats (*Avena fatua*) the operator could switch on pump 2 and pesticide container B allowing the spot treatment of the patch with an appropriate herbicide. Section 4.10 investigates the possibility of patch treatment of pesticides using the ability to switch between different products.

Since the dose rate can be altered on the move, different dose rates can be applied for differing levels of infestation, on different soil types and on headlands; conservation headlands, for example, are currently being actively promoted by the British Agrochemical Association, the Game Conservancy and English Nature. The weeds within the headland could be suppressed by a reduced application of herbicide at the same time as applying herbicide at the recommended rate to the rest of the field. Table 6.1 provides examples of varying dose rate according to soil type; in the case of chloridizan (Pyramin), for instance, when the operator moves from medium or heavy soil to light soil the application rate could be reduced from 5 kg to 1.7 kg/ha; in addition to the environmental advantage in reducing pesticide use there would be a financial saving.

The use of an injection pump and controller allows the operator to select the exact rate per hectare of pesticide required. The ability to select the dose rate overcomes the problems of calculating the exact quantity of pesticide required for an unknown field size and may well therefore reduce the dangers associated with accidental spillage when decanting pesticide into the tank and reduce the need for disposal of any surplus spray.

The injection sprayer has the considerable advantage that the operator never needs to wash out the main tank since it only ever contains water. This process on a conventional sprayer can be potentially hazardous, because the operator is at risk from contamination with dilute pesticide. Traditional washing out is also expensive in terms of labour and may well reduce the time available for spraying. With an injection sprayer the operator refers to the distance remaining indicator on the controller and at the appropriate time switches over from pesticide to rinse water, thus rinsing out the sprayer pipes before leaving the field. This pipe system should have the advantage of reducing environmental pollution when compared with conventional sprayers.

6.2 THE LIMITATIONS OF DIRECT INJECTION SPRAYERS

Long term field trials on farms have shown four major problems with injection sprayers.

6.2.1 Safety

When a conventional sprayer is applying pesticides, the pesticide is diluted in a large quantity of water in the sprayer tank. The attachment of a direct injection system to a sprayer results in pesticide concentrate being carried on the side of the sprayer. The attachment of the pesticide container to the suction probe requires a safe and secure coupling as any leaks due to cross-threading or container inversion could expose the operator to pesticide concentrate and pollute the environment.
The mounting of pesticide containers on the side of a sprayer that has to travel on public roads could also lead to possible danger for other road users, if the side of the sprayer were in collision with another vehicle or a gate post. The containers need to be robust and non-corrodable and enclosed in a strong lockable steel cabinet fitted with a sump able to retain any spillage. The transporting of

hazardous liquids on the highway is controlled by strict transport regulations, all the requirements of which must be met. The use of a pump generating enough pressure to inject pesticide into a sprayer results in the pipe from the pump to the mixing chamber operating at 4-5 bar pressure. Since a fracture in the pressure pipe could result in a major accident, it should be sheathed with braided pipe.

6.2.2 Closing the system

The present wide range of container sizes pose some problems in the use of injection sprayers. The often small containers in which the pesticide product is supplied need decanting into the large containers carried on the injection sprayer. A filling station having an electric pump and probe, may be used but the operator is still at some risk of contamination; a fully closed transfer system would avoid this. On large farms and contractors' services many containers may be used, especially with complex spraying programmes, (Table 6.2) each of which exposes operators to some risk when being filled.

Results from several studies show that the operator is at the greatest risk every time a container is opened or being rinsed, section 2.1.1. Spillage of concentrated pesticide may damage or even kill crop plants and also increase environmental pollution, Craigmill (1982) cites the case of groundwater contamination with chlordane through back siphonage while an operator filled the mixer tank; similar

contamination could follow carelessness when transferring concentrate from one container to another.
A closed transfer system is needed for the injection system that is easy to operate, simple in design and relatively inexpensive. Appendix D contains a report reviewing closed transfer systems for crop sprayers in California where closed systems have been developed for the safe transfer of the more toxic pesticides. Connecting a filled container to the injection sprayer used in these trials requires a simple coupling, Appendix B, which eliminates the need for decanting and measuring. Instead the operator sets the application rate on the cab-controller whicg greatly reduces the time usually taken to measure and decant pesticides which can sometimes take even longer than the time required to fill the water tank.
Surveys of applications with conventional sprayers, section 2.1.2, show that errors do occasionally occur in accurately measuring the amount of pesticide and diluent, errors that would probably be reduced or prevented if the operation were more fully automated.

Pesticide container rinsings that cannot be put directly in the spray tank are still difficult to dispose of safely and therefore the ultimate closed transfer system has to be the returnable re-usable container. Any pesticide remaining in the container at the end of spraying can be returned to the store for later use. Ideally the containers would be returned to the supplier for refilling with the same product, thus eliminating the need for thorough rinsing; this would also remove the present difficulties with the disposal of empty used containers.

6.2.3 Containers: the problem of disposal

The injection sprayer needs to be supplied with enough pesticide to match application rate and water tank capacity. For example, a sprayer with a 2000 litre tank, injecting pesticide at 2.5 l/ha into 200 l/ha of water would cover 10 ha per fill and need 25 litres of pesticide. Pesticide is available in various pack sizes, from 250 ml to 25 litres but most packs are between 1-10 litres capacity. An injection sprayer would need a container in excess of 25 litres to maintain sprayer output while spraying 10 ha (Appendix A16-33).

The Royal Agricultural College farms comprise 740 ha of commercial mixed cropping. Pesticide cost on a total of 326 ha of Autumn sown cereals averages £82.00/ha. Table 6.2 shows the quantities used, the most frequently used products and their pack sizes. Diflufenican plus isoproturon (Javelin) is packed in 5 litre containers. 525 litres were used in 1989-90, resulting in 105 containers each needing decanting, washing out and disposing of, a tedious and time consuming operation putting the operator at risk from splashes of both concentrated and dilute pesticide, and the environment at risk from the disposal of any containers that are not washed free of pesticide.

Thus it can be seen that the large number of pesticide containers used on farms results in a major disposal problem. A survey of 805 pesticide applicators in 38 States of America, (Gilding, 1988), showed that disposal of containers was a major issue. 63% of commercial and 52% of private applicators expressed support for returning empty containers to approved collection points for subsequent safe disposal.

The spray application Code of Practice, (MAFF/HSC, 1990), suggests that containers be disposed of by burying on the farm or at a local authority disposal site. Burning of containers is now virtually impossible since farms came within the requirements of Clean Air Acts of 1956 and 1968. Some ways of disposing of empty containers are to return empty, washed containers to the supplier for disposal, to arrange collection drives in farming areas, recycle the plastic containers or dispose of them in public landfill sites. The major drawbacks are ensuring the containers are thoroughly rinsed and the cost of the process in energy terms.
The use of re-usable containers would address the current problems and offer the following advantages:

a) it removes the disposal problem from the land, be it on a farm or local authority land-fill site.

b) it eliminates the problems of operator and environmental contamination associated with washing out containers.

c) it prevents the container being used for other purposes.

d) with direct injection sprayers, only the amount required for the application would be used, thus reducing waste.

A logical end result of having many returnable re-usable containers would be a common closed transfer system with a dry break connector to reduce operator contamination. A leakproof connector with a backflow preventer avoids fraud or contamination, allows part-used containers to be returned and the farmer credited. A sealing tag prevents tampering and a stamped serial number helps deter theft (of growing importance in the UK). The containers are refilled with the same product thus eliminating rinsing and a small agitator can be used to reduce the possibility of the contents settling out. The container could be made robustly in stainless steel, similar to a beer keg, thus allowing a large number of return journeys from the filling company to the farm. In the USA a number of companies offer re-usable containers of 57-416 litres.

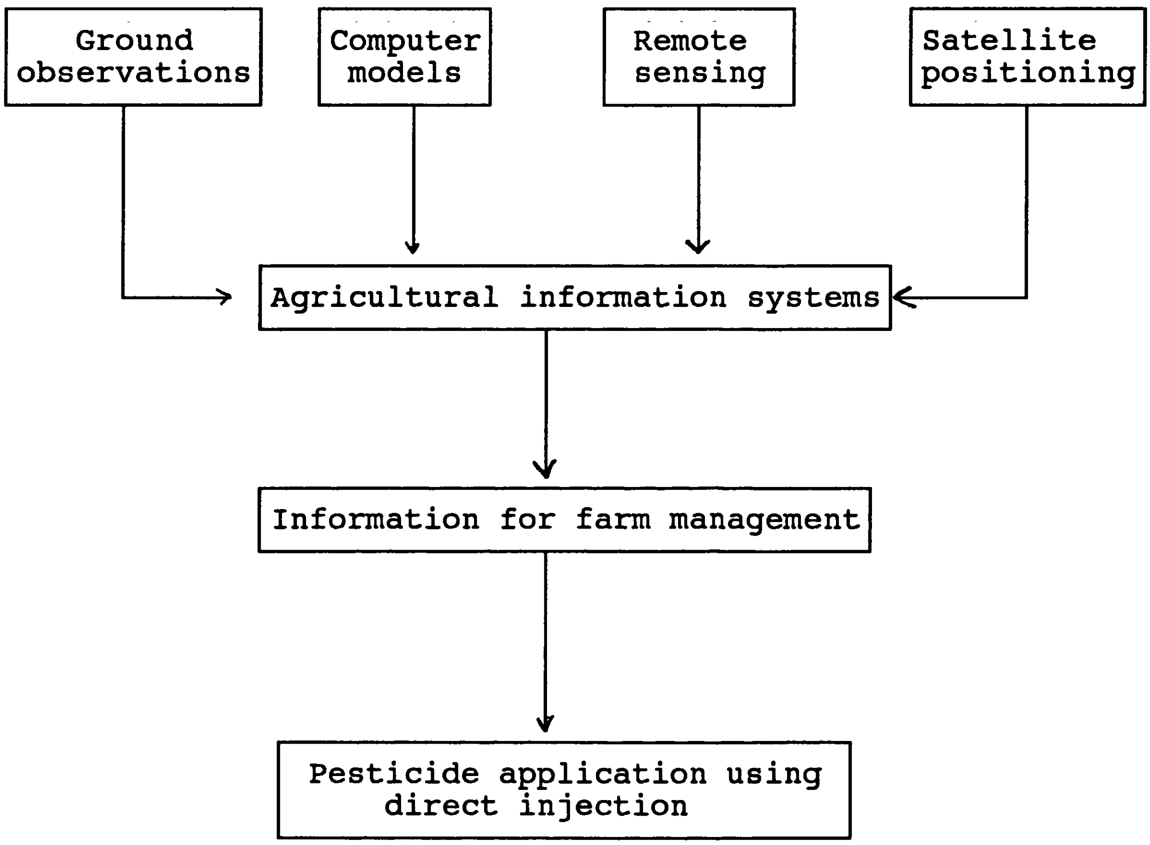
The returnable, re-usable container appears to offer the most satisfactory solution for the farmer and the environment. Other industries already use returnable containers for safety and economic reasons, eg, beverages and acids. Returnable containers are already in use on farms for silage additives, acetylene, oxygen and LPG. While the injection sprayer could eliminate the environmental problems associated with tank washing, the use of returnable re-usable containers could eliminate the problems already described that are associated with pesticide transfer. Eventual disposal after many return trips would probably be at source.

6.2.4 The capital cost

The direct injection sprayers available in the UK are still relatively expensive. Farmers are facing a period of great financial uncertainty and the added expense of an injection system may be difficult to justify, but the larger farmers and contractors view injection systems as being cost-effective due to the advantages previously mentioned in Section 6.1.

Discussions with the manufacturers of the systems under development and manufacture, (Landers, 1988), highlight the difficulty of achieving pump accuracy at a modest cost. To obtain accuracy with pesticides of varying viscosities requires an extremely well made pump, which is inevitably expensive. The other material costs, such as electronics, can probably be manufactured at an acceptable price, provided the numbers of circuit boards ordered are large enough. The wide range of organic solvents used in pesticides creates difficulties for component manufacturers, especially of pump seals and plastic parts, in finding sufficiently resistant materials. Improvements in design, such as finding simpler means of pesticide injection possibly using air pressure will, it is hoped, result in less expensive systems in the future.

Figure 6.1 CAPA - Computer assisted pesticide application



6.3 THE FUTURE: CAPA - COMPUTER AIDED PESTICIDE APPLICATION

Public and government pressure to reduce pesticide use will continue and legislation to protect the environment will become more severe and demanding and so the further development and more general introduction of direct injection sprayers seems likely. When this occurs CAPA will offer many advantages to the users of such sprayers.

6.3.1 Computer-assisted information gathering

Information technology can be used to help the farmer gather information about the health status of his crop and compare field conditions with a computer model. The resulting farm management information can be used to develop a crop spraying programme. Figure 6.1 shows the role of information technology for a pesticide application system. CAPA comprises the following:

i) computer based information systems

There are several new information based programmes available to the farmer using human logic to provide help with questions such as planning strategy, pesticide application and machine selection. Information technology can be used to record data from field observations on soil type, crop response to pesticides and crop yield.

Computer models can be used to simulate crop production, allowing the farmer to compare the model with the field information, (Baandrup and Ballegaard, 1989). Smith and

Webster (1986) concluded that simulation models should display more than just 'spray' or 'don't spray', they should include monetary values of alternate strategies e.g. the opportunity cost of labour. Farmers are more interested in the expected loss rather than the variability of loss. Machinery selection models are available for comparing spraying systems. Landers (1992) devised a model to examine the effect of changes in the operating parameters of a spraying system, section 3.11.

ii) data acquisition in the field

There are a number of systems available for data capture and retrieval.

a) Soil mapping

Detailed soil maps can be constructed for the farms. A soil survey will result in a detailed plan of the various soil types so that the farmer can appraise the land, cropping and fertilizer policy. For example, pesticide requirements vary from one soil type to another certain pesticides being used at higher rates on organic soils compared to sand soils to compensate for binding by adsorption.

b) Crop reporting

Hand held data capture systems are being developed by a number of manufacturers. The introduction of a data logger will eliminate transcription errors, provide the opportunity to review assessments immediately and cut down time delays between information collection and the final report, greatly reducing costs; such an integrated approach to information technology was reported by Dickson and Talbot (1985). The hand-held data logger can be used with a position indicator, so that weed or diseased patches can be identified and located for spot treatment. For example, the crop walker logs in the beginning of a patch of wild oats (*Avena fatua*) and presses the location switch on. When the patch finishes the walker presses the location switch off; the spot treatment injection sprayer will then carry out the instructions it is given when it passes over the positions. The data can also be downloaded into an office computer.

c) <u>Down the row identification of soil organic matter</u>

Gaultney et al (1989) developed a real-time soil organic matter sensor which used a narrow band light source and measured reflectance from the soil with a photo diode. Sudduth et al (1990) developed a prototype sensor using near infra red reflectance techniques to determine the organic matter content of the soil surface. The application rates of soil acting herbicides must often be increased on high organic matter soils because the cation exchange capacity of the organic matter increases the adsorption of a herbicide and decreases its effectiveness.

A microprocessor can be developed to interface with the controller of an injection crop sprayer.

d) Down the row identification of weeds

Petry and Kuhnbauch (1988) developed a technique for the discrimination and quantitative registration of a weed population. Different spectral information of the plant and soil was used. A video camera was used to deliver separate image signals for the red, green and blue parts of the spectrum which then became digitised in a video card and a weed cover gradient was devised. Thompson et al (1990) concluded that a weed detection system based on finding plant material between rows of cereal crops was very sensitive to crop canopy cover; detection was only possible when crop density was low.

e) Crop yield meters

A number of combine harvesters have been fitted with grain yield meters. The operator is able to monitor crop yield and obtain a print out of the results. Selected areas of the field can be monitored and farm trials carried out. The farmer is able to use this information in developing a computer cereal model and thus the effect of pesticides applied to any particular part of the field can be closely monitored.

f) Satellite positioning

The position of a crop walker when recording data on the health status of a crop is very important for the spot treatment of weed patches. Similarly the position of the combine harvester is also important when measuring grain yield from trial plots. As the injection sprayer drives towards the patch of weeds or disease a vehicle position indicator can inform the sprayer controller and switch on a particular injection pump and spray pesticide as and when required.

Shmulevich et al (1987) and Gorham and MacLeod (1991) developed a field machinery guidance system using a scanning laser based upon triangulation geometrical positioning. Choi et al (1990) described an automatic guidance system based upon two position sensors designed to follow a predetermined path. The use of satellites for marine use has enabled sailors to find their exact position anywhere in the world. Satellites are used extensively for military purposes and systems exist which give pinpoint accuracy. As more systems are made available by the military and as other systems are developed, so satellite positioning will become affordable.

6.3.2 Information processing

The farmer is able to use the data acquisition systems information to help in the decision making process. The farmer can compare the ground data with the computer simulation and decide on a pesticide strategy.

A 'smart card' system could be developed which would allow information to be downloaded from the office computer. The card would contain information about the weeds and disease status and its position in the field. A patch of weeds or disease could be spot treated with pesticide as the sprayer passes. As the weed infestation is passed the sprayer could be switched off. Satellite positioning would indicate the grid reference. The 'smart card' could contain information on the level of infestation, allowing the pesticide to be applied at varying levels according to the degree of infestation.

The controller of the injection sprayer enables the farmer to carry out these functions manually at present, but the development of a control board to allow automation is quite feasible. A printer could be installed to allow the farmer to know the exact quantities of pesticide applied and the area sprayed which would enable precise financial control to be retained.

Computer aided pesticide application (CAPA) will result in more appropriate use of pesticides and rates being used, with an overall reduction in application rates, which would be welcomed by environmentalists, legislators and farmers. CAPA will enable the farmer to be better informed regarding his pesticide application strategy and enable him to improve his decision making skills.

6.4 FUTURE RESEARCH

Laboratory and field trials showed that pump output varied according to the pesticide used and the temperature; a record of the effect of different pesticides on pump output in conjunction with the dose calibration figure for the in-cab controller needs to be developed and added to the user manual.

The injection system can be purged satisfactorily with water but further trials with proprietary 'tank cleaners' should be considered. A video camera fitted to a computer using an image analysis programme could be used to monitor the change in spot density thus giving a quantitative analysis of the wash solution spots on the TLC plates. Trials were carried out with isoproturon (Hytane), a very cohesive pesticide but further tests could be carried out to calculate the quantity of water or 'tank cleaner' necessary to purge the system of other cohesive pesticides. Alternative laboratory analysis methods such as Gas Liquid Chromatography could be used.

The major problem of delay in pesticide reaching the first and last nozzle remains; engineering methods such as small bore pipes, placing the injection pumps and mixing chamber nearer the boom need to be evaluated.

Investigation of simpler means of pesticide injection using air pressure or mechanical pumps, may result in less expensive injection systems, but robust and reliable components must be used to ensure accuracy and longevity.

Further work should be carried out to monitor the occurrence and location of patches of weeds and diseased areas in arable crops with hand-held computers using geographical positioning systems; the resultant information should be used to develop an integrated package for computer-aided pesticide application. Satellite positioning of tractors and sprayers needs to be evaluated on farms.

6.5 CONCLUDING REMARKS

Increasing public awareness and concern about the use of pesticides and their impact upon the environment will result in pressure upon the legislators to act to restrict their use. Direct injection systems will facilitate the implementation of existing and proposed EC legislation to reduce both pesticide use and operator and environmental contamination. The ability to alter dose rates and change the mix of pesticides being applied, on the move, should result in less pesticide being used, which is in keeping with current legislation in parts of Scandinavia and The Netherlands. Reducing pollution from agriculture within the member states of the EC will result in further legislation and stricter control. In Spring 1992, the German Government launched a 30% grant scheme for the purchase of injection sprayers for pesticide sensitive areas. The purchase of injection sprayers by farmers could well be legislation-driven.

As changes in EC policy and other external pressures affect arable farmers further, there will be an even greater need to consider the costs of production. The spot treatment of local weed infestations has great potential for reducing pesticide use, resulting in financial savings for the farmer and fewer pesticide disposal problems, while achieving results similar to overall herbicide application.

Injection systems can easily be fitted to conventional sprayers, and because they do not directly alter the actual spraying technique, they do not require additional legislation before being adopted.

Computer assisted pesticide application is certainly feasible as the technology necessary for the development of spot or patch spraying already exists. The system should enable the farmer to be better informed and more precise in his decision making.

Although the adoption of direct injection sprayers and returnable containers will incur some extra costs throughout the farming community, there will be savings also, and on balance it is considered that the advantages will greatly outweigh any disadvantages.

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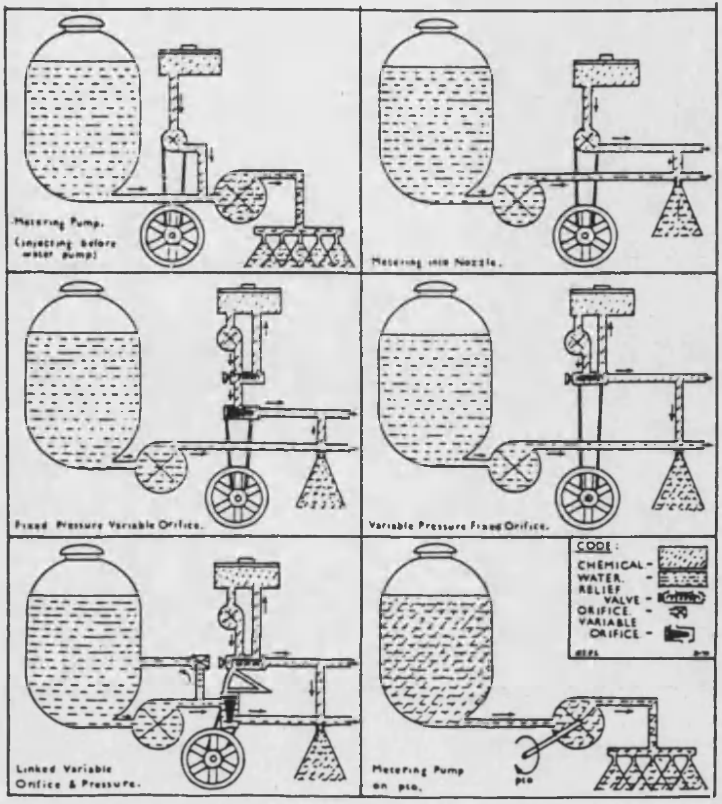
APPENDIX A

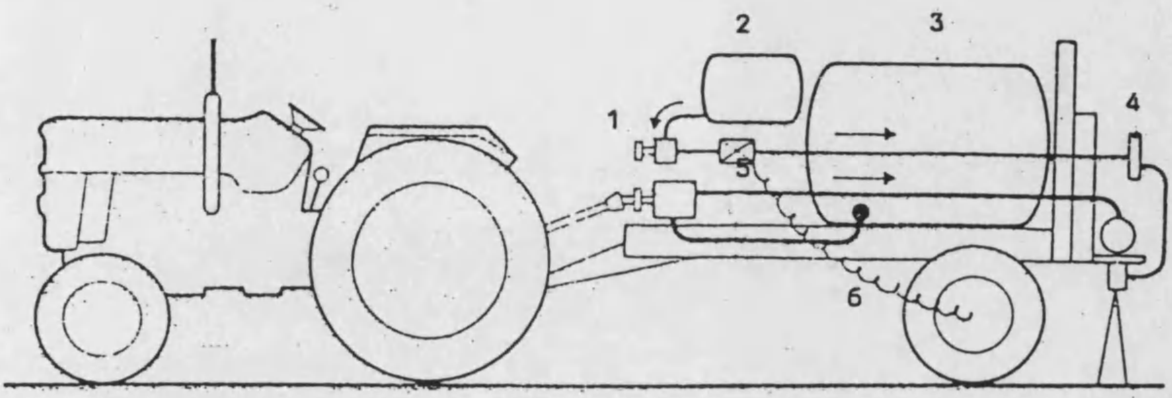
THE CHRONOLOGICAL DEVELOPMENT OF DIRECT INJECTION SPRAYERS



The above diagrams show various arrangements for crop sprayers.

Figure 1 is a land wheel driven injection pump, mixing the pesticide and water in the main water pump. Figure 2 shows the injection of pesticide at the nozzle. Figures 3 and 4 illustrate the use of fixed pressure, variable orifice and variable pressure, fixed orifice systems, using land wheel driven pumps and injecting pesticide at the nozzle. Figure 5 shows a sophisticated sprayer, where the variable orifice, controlled by a land wheel, is linked mechanically to a pressure variator on the water supply. Figure 6 illustrates a metering pump driven from the p.t.o.

Reference: Amsden 1970



A servo operated system with separate pesticide and diluent tanks and pumps

1- pesticide pump	**2- pesticide tank**
3- water tank	**4- injection manifold**
5- control unit	**6- speed signal**

The above diagram shows pesticide and diluent being kept in separate tanks with separate pumps. Pesticide is being injected at a higher pressure from a pump, through a manifold into the sprayer nozzles. A speed signal controls the amount in proportion to forward speed. This type of system has been used on the Fison spray train for British Rail.

References: Matthews (1979) and Amsden (1970)

A.2

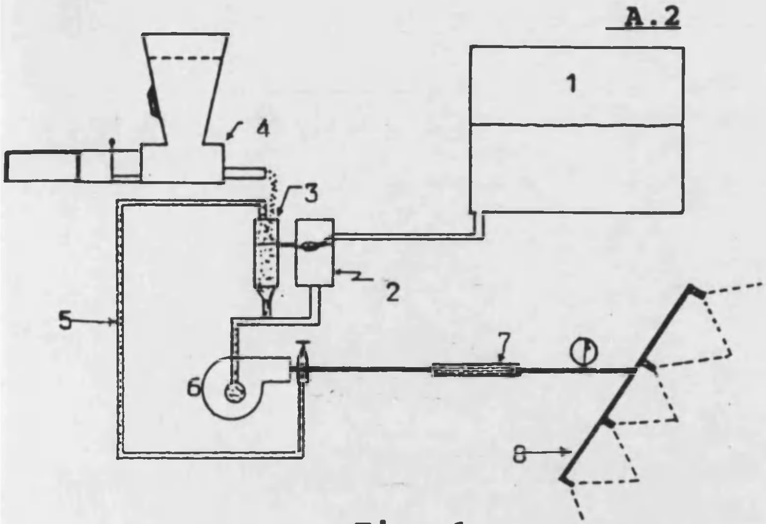


Fig. 1

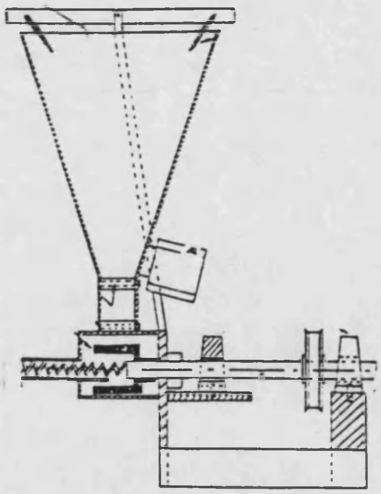


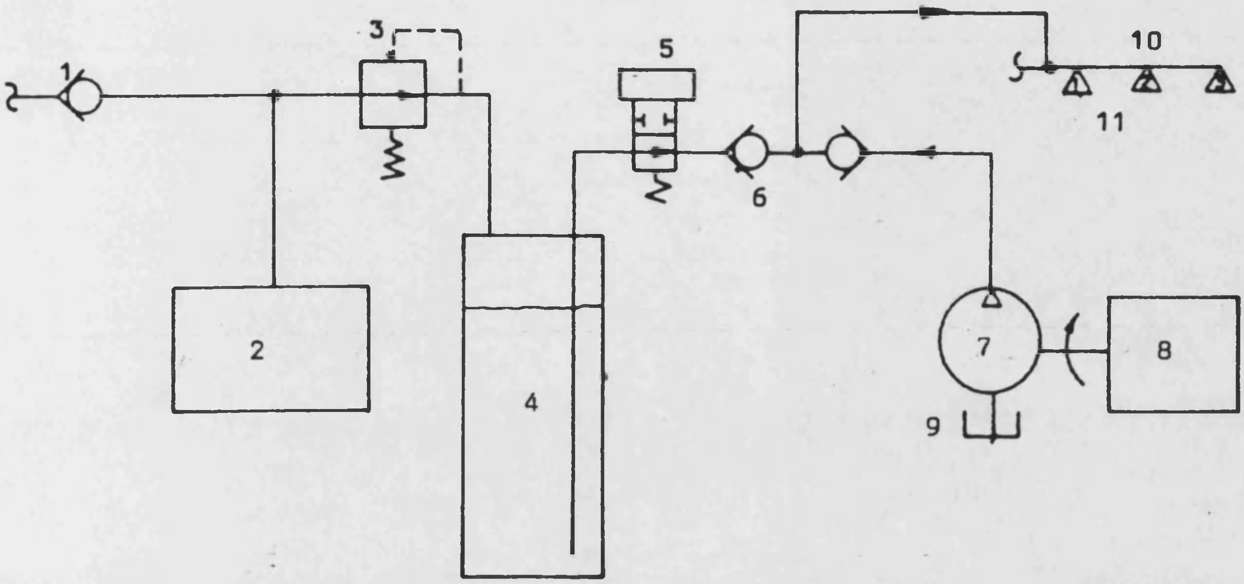
Fig. 2

1- water tank
2- water level control
3- mixing tank
4- pesticide metering unit
5- bypass
6- pump
7- inline mixer
8- boom

A dry pesticide metering unit, Figure 2, Hare et al (1969) was developed for applying dusts. The unit comprises a vibrating hopper and a dispensing unit using a spring auger driven by a variable speed motor for rate control. Figure 1 shows a schematic of the sprayer. The water flows from the tank to a water level control tank; a float valve ensures the correct amount. Adjacent to the level control tank is a mixing cylinder in which water rises to the level obtained in the level control tank. Pesticides are metered into the mixing cylinder, initial mixing occurs by the pump recirculating the pesticide and water. A pressure regulator maintains spray pressure and bypasses excess liquid for recirculating back into the mixing cylinder. The in-line mixer comprises a series of bow-tie shaped elements welded together, alternating right and left-hand pitch. A centrifugal water pump was used.

References: Hare et al (1969) and Harrell et al (1973)

A.3



A schematic diagram of a constant pesticide application rate sprayer model for laboratory use.

1- air supply	**2- air accumulator**
3- pressure regulator	**4- hydropneumatic tank**
5- on/off solenoid	**6- check valves**
7- pesticide pump	**8- motor**
9- pesticide reservoir	**10-boom 11- nozzles**

The system consisted of a Hypro model C5315 double acting piston pump driven by an electric motor. The pesticide was pumped from the reservoir to the mixing junction just before the booms. An air supply, at 689 kPa, pressurised the diluent in the hydropneumatic tank. The pesticide pump was operated at a speed directly proportional to simulated ground speed and the hydropneumatic system was operated at a constant pressure by means of a pressure regulator. For field use the diluent supply would probably be pressurised by an hydraulic pump and the pesticide pump powered by a vehicle ground wheel.

Reference: Vidrine et al (1975)

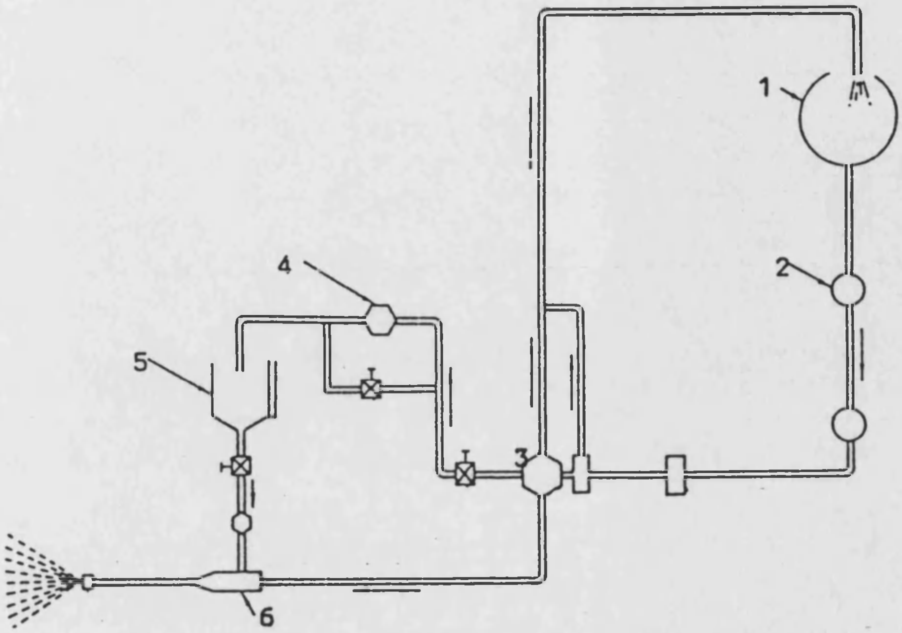


Fig.1 Schematic diagram of the induction system

1- Water tank 2- pump
3- control valve 4- level control valve
5- mixing chamber 6- jet pump 7- nozzle

Diluent is pumped from the water tank via a pressure regulator to a control valve. In one position, the control valve directs liquid under pressure to the jet pump and level control valve. When moved to its other position, the control valve diverts all flow to the tank while maintaining operating pressure at the control valve. Liquid level probes in the mixing chamber, through an electrical control system, actuate the level control valve to maintain a constant liquid level.

(Continued in A. 4b)

A.4b

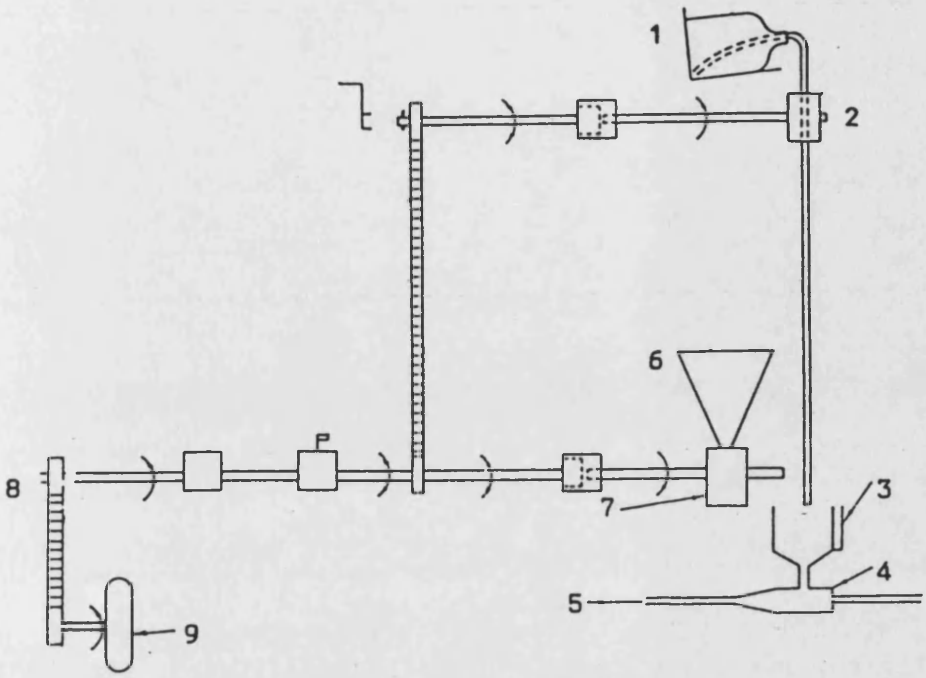


Fig.2 Schematic diagram of pesticide metering system

1- liquid container 2- peristaltic pump
3- mixing chamber 4- jet pump 5- nozzle
6- powder hopper 7- metering unit
8- drive shaft 9- land wheel

Injecting liquid pesticide:

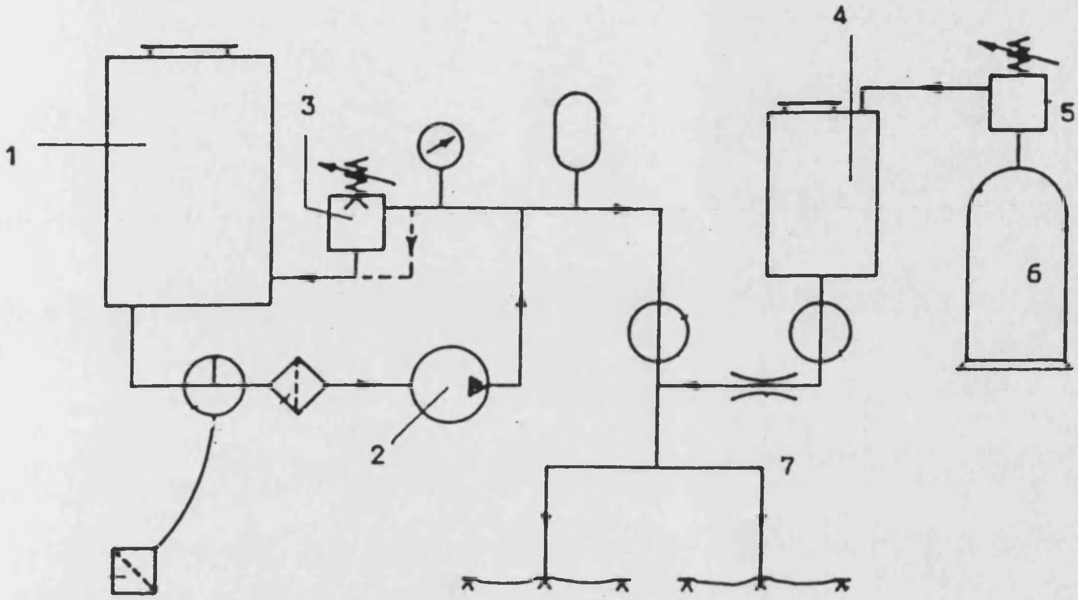
The peristaltic pump is connected, via a drive shaft, to the land wheel. Pesticide is withdrawn from the original container and pumped to the mixing chamber.

Injecting dry pesticide:

The powder dispenser developed by Hare et al (1969) was used to meter powders into the mixing chamber.

References: Peck and Roth (1975)
Hare et al (1969)

A.5



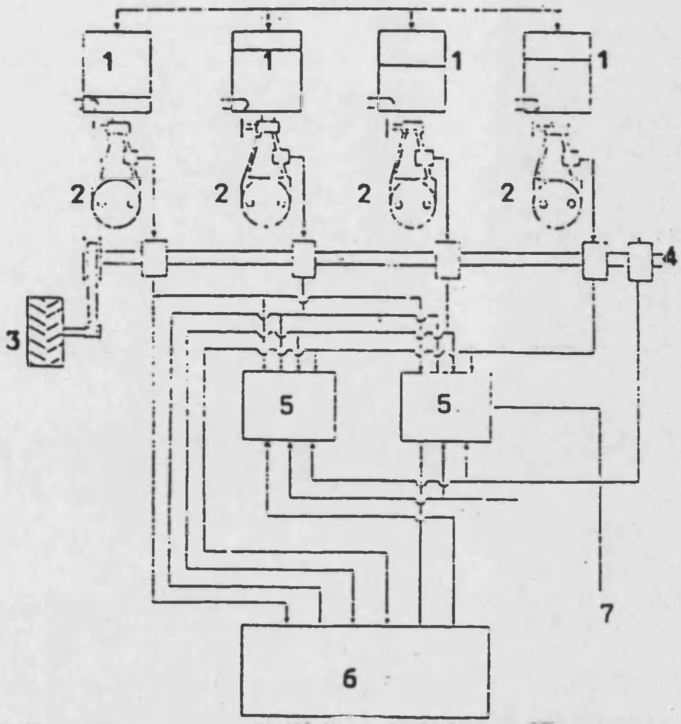
Schematic diagram of the Betanal injection system

1- water tank	**2- water pump**
3- pressure regulator	**4-pesticide tank**
5- gas pressure regulator	
6- compressed air bottle	**7- boom**

The Betanal system was developed at IMAG, Holland in 1976. The sprayer comprises a tank containing clean water which is pumped to an inline mixing chamber by means of a water pump and pressure regulator. Pesticide is placed in the pesticide tank. The tank is pressurised by compressed gas via a gas pressure regulator. The original model used propane gas as the pressure source. In 1980 the system was improved by the use of an air compressor to create the gas pressure.

Reference: Hoenderken (1988)

A.6



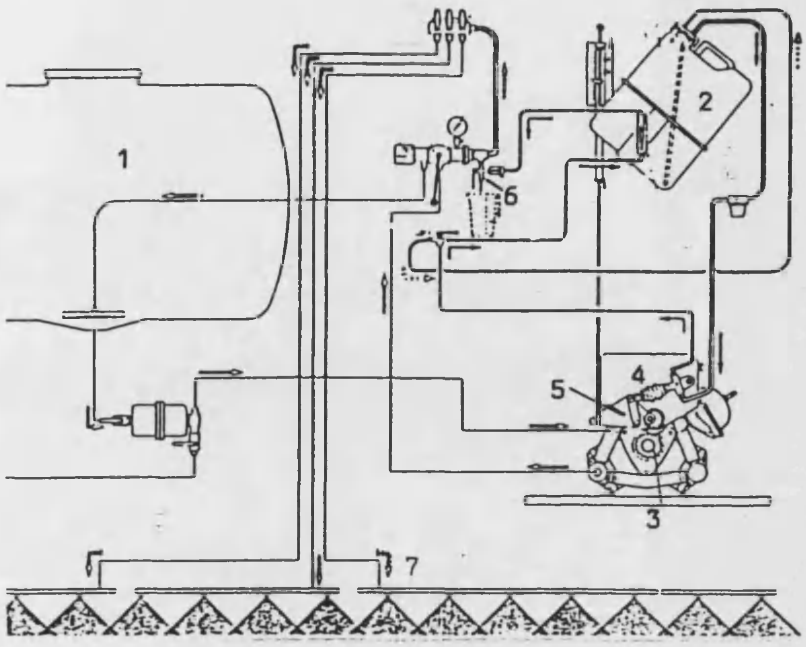
Schematic diagram of a ground driven pesticide metering system

1- pesticide containers | **2- metering pump**
3- land wheel | **4- water pump**
5- mixing chamber | **6- spraying chamber**
7- recirculated spray

The recycle sprayer was designed to straddle fruit bushes/trees. Pesticide is pumped from the original containers by metering pumps. The pumps are land wheel driven. Pesticide is injected into one or more mixing chambers, joining water supplied by a land wheel driven pump. Fans, mounted in a horizontal air chamber direct the air blast/pesticide on to the fruit trees. Any excess spray and run-off is recycled and recirculated.

Reference: Tennes et al (1976)

<u>**A.7**</u>



The EHO injection system

1- water tank **2- pesticide container**
3- water pump **4- injection pump**
5- stroke length control **6- injection point**
7- booms

Pesticide is withdrawn from the original container by means of a small piston pump. The brass and steel pump is driven by the p.t.o input to the water pump. The piston stroke length can be adjusted to alter dose rate. The pesticide can be injected into the water line just before the boom valves.

References: EHO (1987) and Cho (1985)

A.8

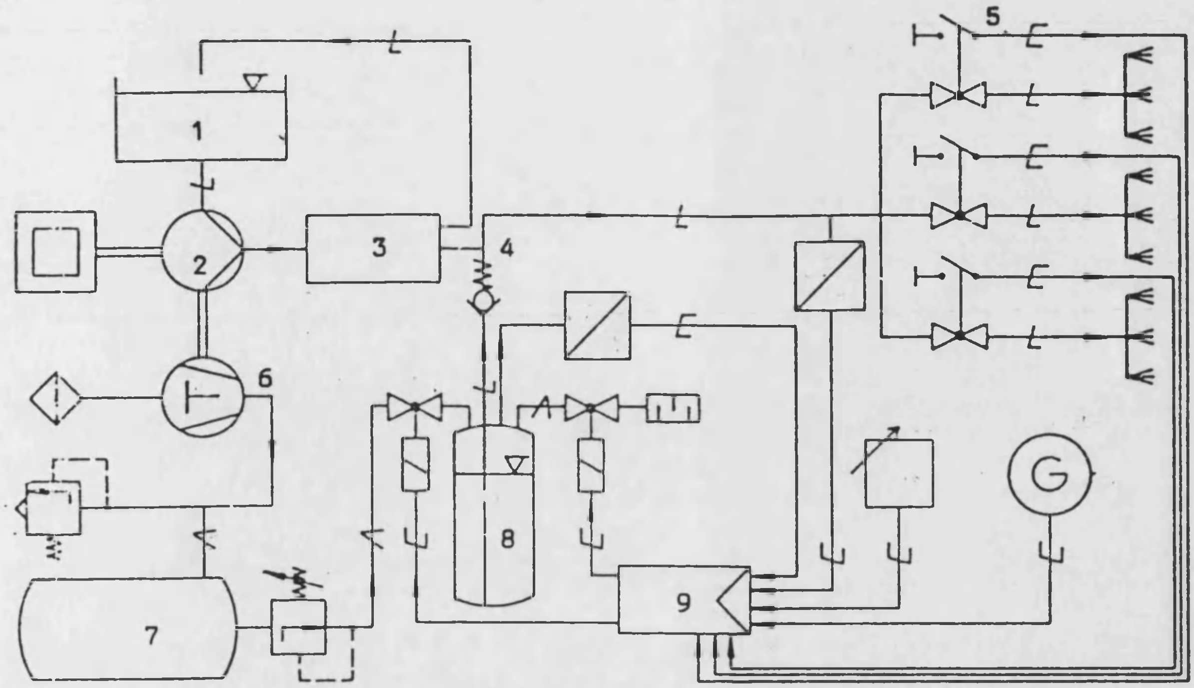


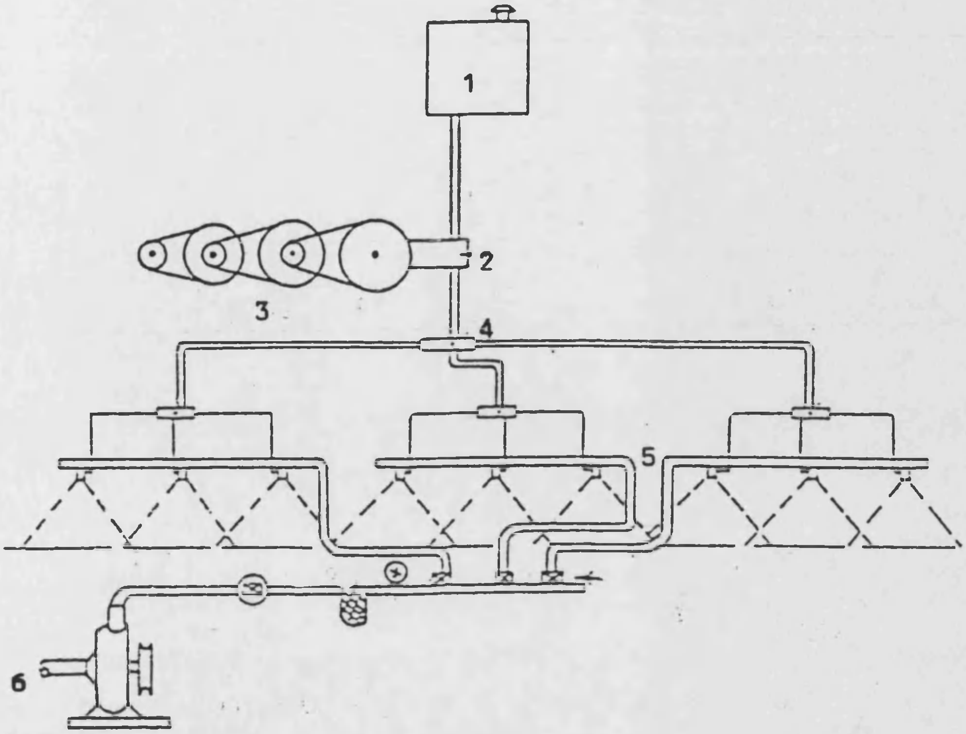
Diagram of a pneumatic direct injection system

1- water tank **2- water pump**
3- pressure regulator **4- injection point**
5- boom **6- air compressor**
7- air tank **8- pesticide tank**
9- controller

The pesticide is contained in a small replaceable pressure tank and injected into the water line by air pressure. Air pressure is created by an air compressor and air reserve maintained in the air tank. Air and water pressure can be monitored by the controller and changes in flow effected by changes in pressure.

References: Schmidt (1983)

A.9



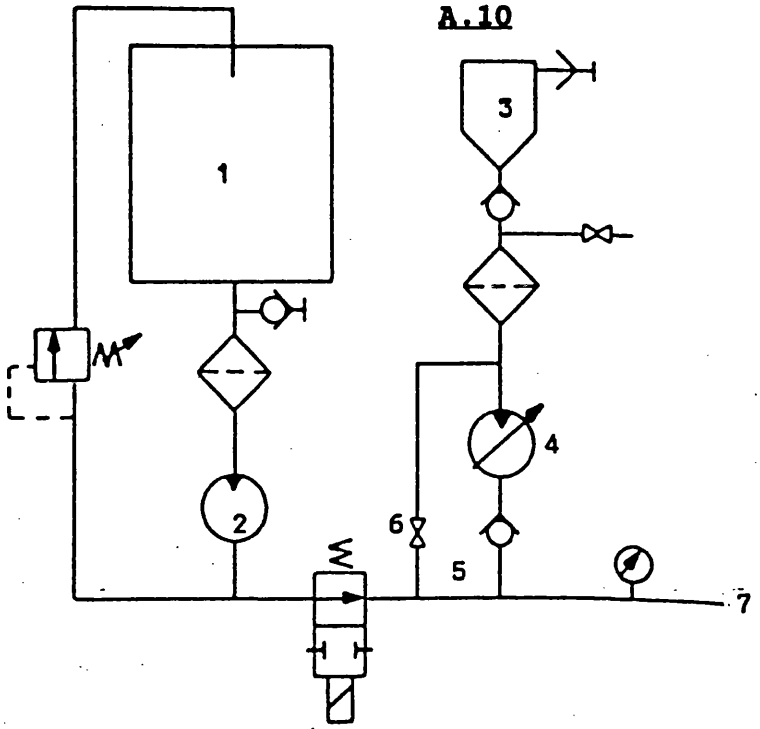
Schematic diagram of the injection system for the Hesston sprayer

1- pesticide container **2- pesticide pump**
3- pump drive **4- manifold**
5- Boom **6- water pump**

Water is supplied from a tank by a centrifugal pump to the booms. Pesticide is injected at the nozzles by means of a John Blue (FA-500) double-acting piston pump. A manifold distributes the pesticide to each nozzle and a land wheel drives the injection pump. A plugged nozzle with holes in the side and no swirl plate gives the best mixing.

Reference: Larson (1982)

A.10



Schematic drawing of the injection system

1- water tank **2- water pump**
3- pesticide tank **4- pesticide pump**
5- injection point **6- flushing valve**
7- booms

Water is pumped from the water tank by means of a p.t.o driven piston pump. A pressure relief valve maintains the desired spray pressure. Pesticide, contained in a 57-litre tank, is pumped by a Hydracone metering pump (Pulsafeeder, Interpace Corp.). Piston stroke length is manually adjusted and pump drive is obtained from a land wheel. Pesticide is injected into the water line close to the boom.

Reference: Reichard and Ladd (1983)

A.11

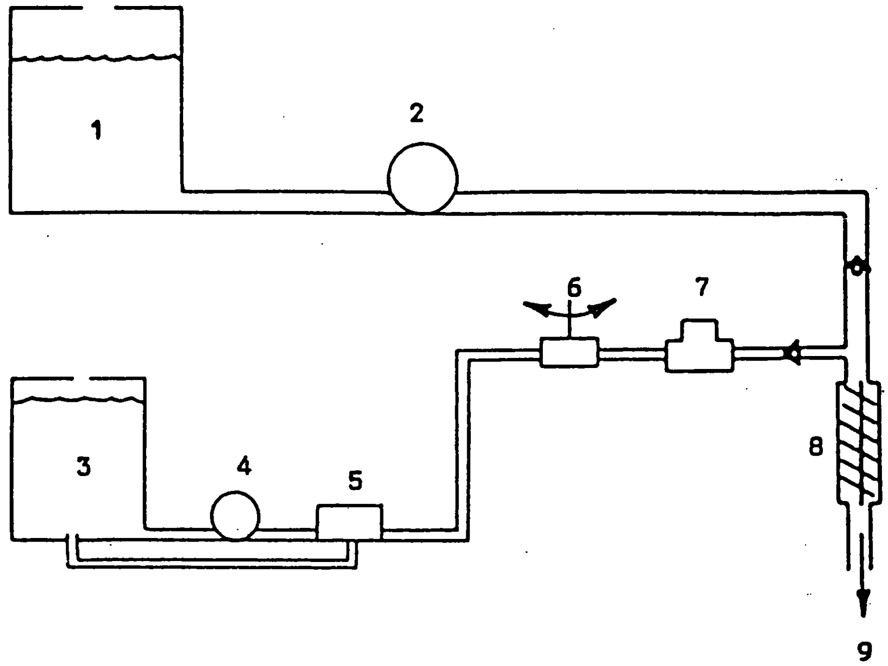


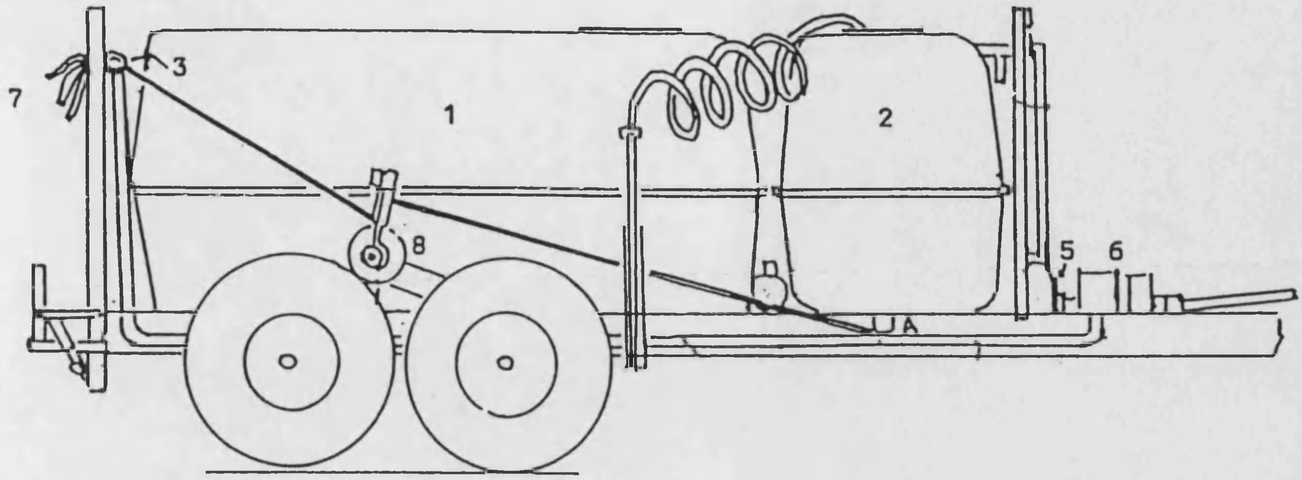
Diagram of a concentration controlled pesticide sprayer

1- water tank **2- water pump**
3- pesticide tank **4- pesticide pump**
5- pressure regulator **6- flow control valve**
7- flow meter **8- mixing chamber**
9- nozzles

Water from the tank is pumped to the mixing chamber. Pesticide from the pesticide tank is pumped to a pressure regulator; any excess is returned to the tank. The pesticide flow control valve is regulated by a controller. One of the inputs to the controller is a feed back signal from the flowmeter; a drag-body type flow meter, using a strain gauge, is used to develop a closed-loop control system.

Reference: Gebhardt et al (1984)

A.12



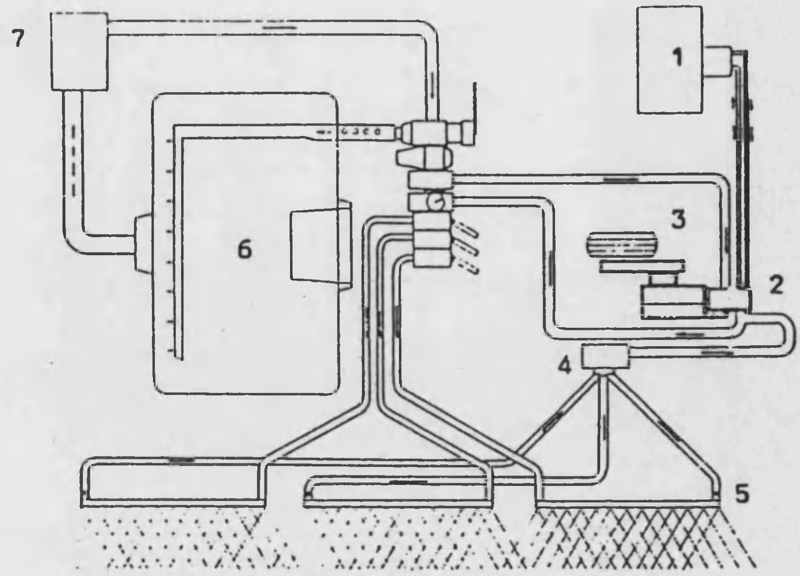
The Australian 'Terramatic' boom sprayer

1- water tank 2- pesticide tank
3- mixing manifold 4- injection pump
5- air compressor 6- water pump 7- booms

Water is pumped from the water tank to the mixing manifold. Pesticide is contained in the pesticide tank and compressed air, provided by the air compressor, keeps the pesticide under a pressure of 180 kPa. A small piston pump, driven directly off the land wheel, injects pesticide into the manifold. Pressurising the pesticide in the tank avoids problems associated with pump cavitation due to varying pesticide viscosities and specific gravity. Injection occurs near the booms by means of venturi inlets. Two pesticide tanks are fitted.

Reference: Humphries and West (1984)

A.13



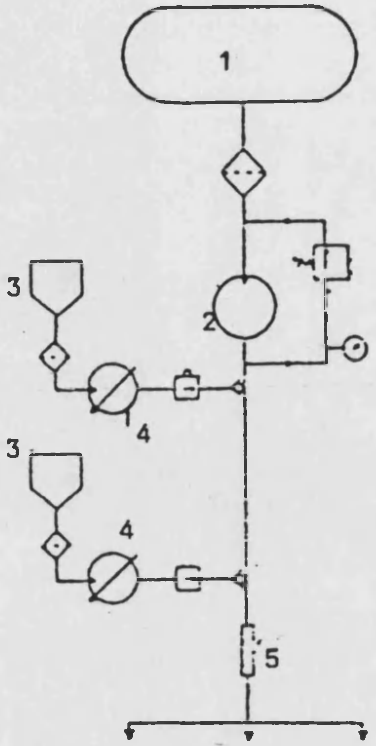
The Conduria GDE injection system

1- pesticide tank 2- pesticide pump
3- land wheel 4- circulation pump
5- booms 6- water tank 7- water pump

The metering pump is driven by a friction wheel running against the tractor drive wheel. Pesticide is placed in a 42-litre tank mounted on the side of the sprayer. The metering pump is a three piston displacement pump, with one double stroke per piston and revolution. The water pump is p.t.o driven. Water flows from the pressure regulator to the injection pump where it mixes with the pesticide. A circulation system takes the solution to the boom and returns excess via the circulation pump.

References: Ostarhild (1984) and Lindner (1985)

A.14



Schematic diagram of the 'improved' injection system

1- water tank **2- water pump**
3- pesticide tank **4- pesticide pump**
5- inline mixer

The EHO injection sprayer from Finland (Appendix A.7) was tested in the laboratory using pesticide mimics. The simple piston pump was found to be unsatisfactory and the following components were fitted to improve the sprayer:-

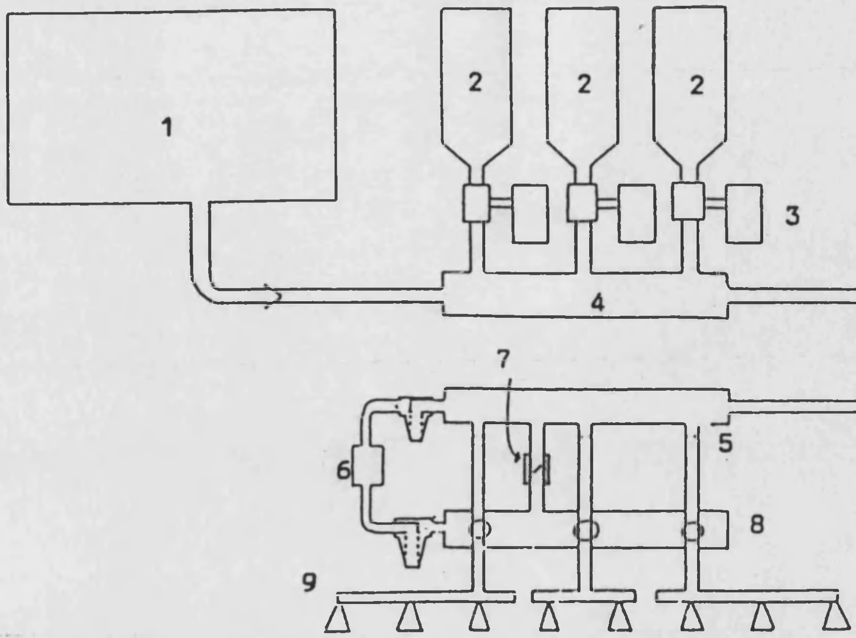
i) the EHO metering pumps were replaced with two diaphragm pumps (model 680 AG-C-C-E, Pulsafeeder, Interpace Corp.)

ii) the piston type water pump was replaced with a centrifugal pump

iii) an inline static mixer was installed to increase turbulence in the lines.

Reference: Cho et al (1985)

A.15



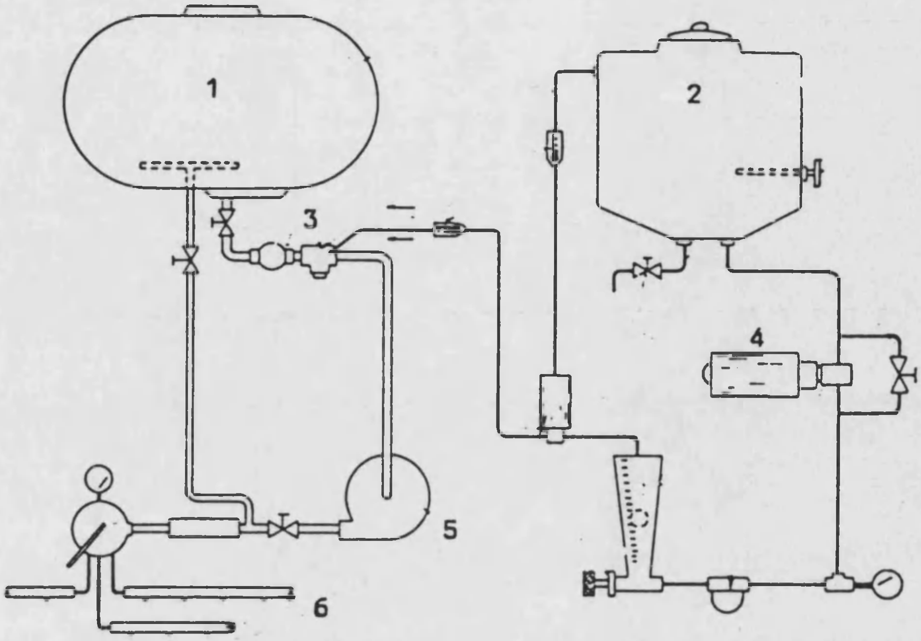
Schematic of the Walsh cci-2000 or the Mid-West Technology cci-2000 injection sprayer

1- water tank 2- pesticide tanks 3- injection pumps
4- induction manifold 5- return manifold 6- water pump
7- butterfly control valve 8- spray manifold 9- booms

Pesticide, contained in the cone bottomed tanks, is pumped by Randolph peristaltic pumps to the induction manifold where it mixes with water from the sprayer tank. The peristaltic pumps are driven by 12-volt variable speed electric motors. By varying tube size and motor speed, the pumps can inject pesticide within a wide range of application rates. The spray passes through the stainless steel return manifold, through the water pump and into the spray manifold. Boom control valves allow the spray to pass to the booms; if a boom is switched off, the spray goes back to the return manifold. An electronic controller allows dose rate adjustments to be made on the move.

References: Grunewald (1986) and Handbury (1988)

A.16



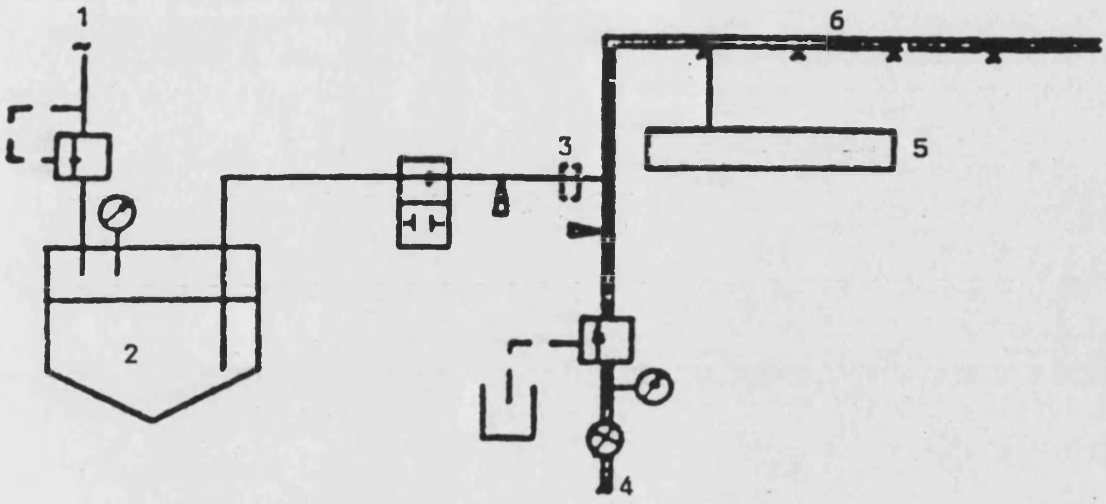
Schematic diagram of the 'Ag-Chem' injection sprayer

1- water tank **2- pesticide tank**
3- injection point **4- injection pump**
5- water pump **6- booms**

Water is carried in the water tank and pumped into the booms. The pesticide is carried in two tanks, mounted on the side of the sprayer. Pesticide is metered by two Flojet piston diaphragm pumps driven by 12-volt electric motors. The pesticide is injected into the water just before the water pump, thus ensuring a good mix.

Reference: PAMI (1986)

A.17



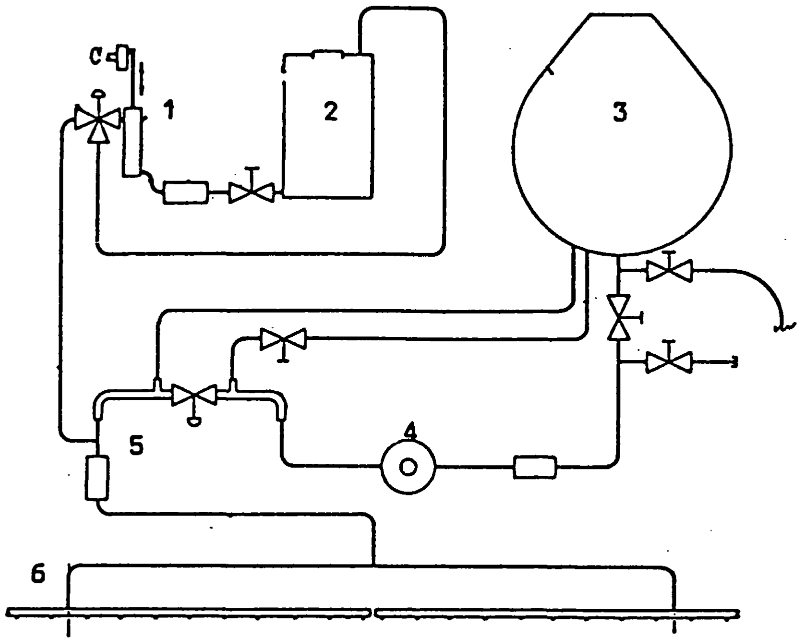
A schematic diagram of the experimental layout for injection development

1- air supply 2- pressurised pesticide container
3- injection point 4- water supply 5- fluorometer
6- boom

A laboratory injection system was devised to measure delay times after the pesticide had been injected. A compressed air supply was used to pressurise the pesticide container. Pesticide was delivered into the injection point via a metering disc which controlled flow rate. Water mixed with the pesticide mimic and the fluorometer detected the presence of Rhodamine B.

Reference: Koo et al (1987)

A.18



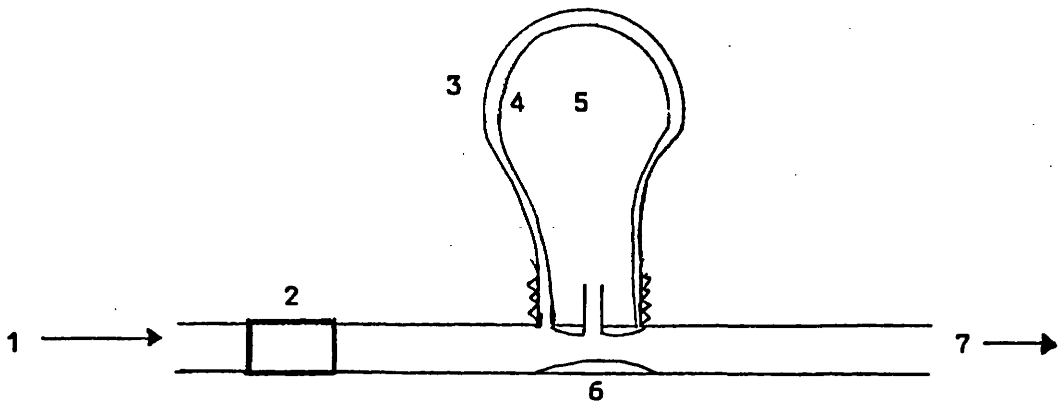
Schematic diagram of the 'Computerspray spot spraying chemical injection metering system'.

1- injection pump	**2- pesticide container**
3- water tank	**4- water pump**
5- injection point	**6- booms**

Water is pumped from the tank to the booms by a ground driven double acting piston pump. Pesticide is pumped by a small piston pump, driven directly by the land wheel, from a 60-litre tank. A vernier scale on an eccentric cam arrangement alters dose rate. The injection point is a simple tee at the manifold to the booms. Mixing occurs due to the inline filter and the boom plumbing.

Reference: PAMI (1987)

A.19



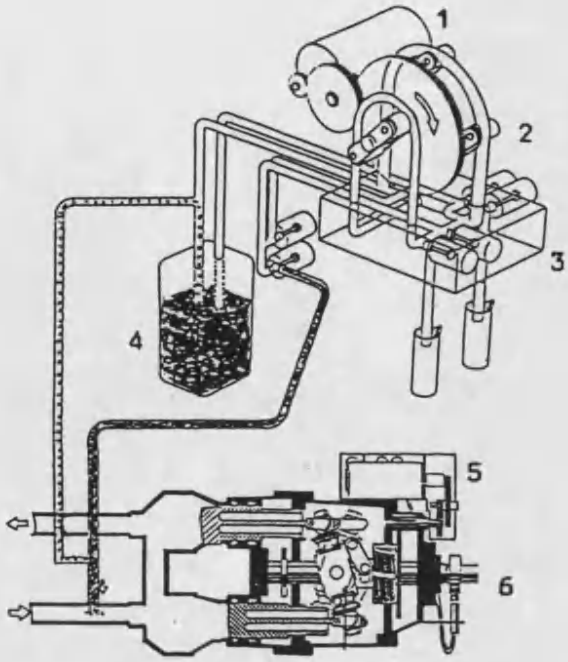
The Down fluid injector

1- water flow from hand operated pump
2- sprayer management valve
3- screw-on pesticide bottle
4- flexible inner bag
5- pesticide
6- venturi
7- flow to nozzle

The Down injector was designed in Australia for use with knapsack sprayers. Water is pumped via a spray management valve which provides a constant pressure at the nozzle. As the water flows through a venturi a small proportion passes through a valve at the top of the bottle and pressurises the flexible bag. The bag is squeezed at a constant pressure and the pesticide flows out at a constant flow-rate via the venturi into the hand lance.

Reference: Crook (1988)

A.20



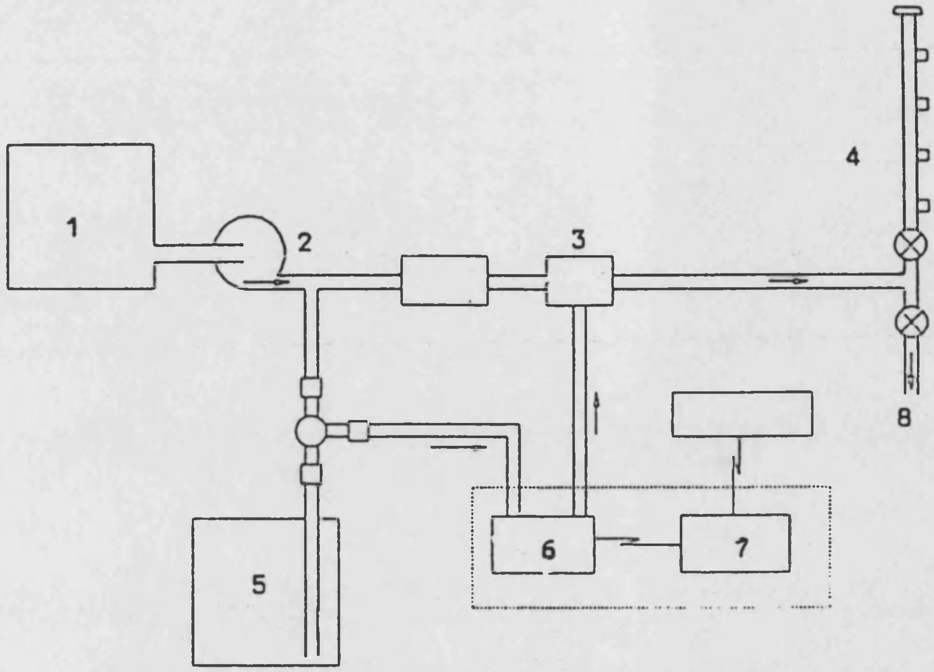
The Vicon injection system

1- electric motor **2- peristaltic pump**
3- valves **4- pesticide container**
5- electric motor **6- water pump**

The injection system comprises a dual tube peristaltic pump. This pump has both a large and small bore tube, which allows the operator to select a wide range of application rates. The peristaltic pump is driven by a variable speed electric motor. The pesticide is removed from the original container via the pump and is injected in the inlet side of the water pump. The water pump is an axial piston pump (swashplate pump) and so the output (dose rate) can be altered according to requirements. The dual tube pesticide pump electric motor and the water pump electric motor can be operated together, thus adjusting output simultaneously.

Reference: Beijaard (1988)

A.21



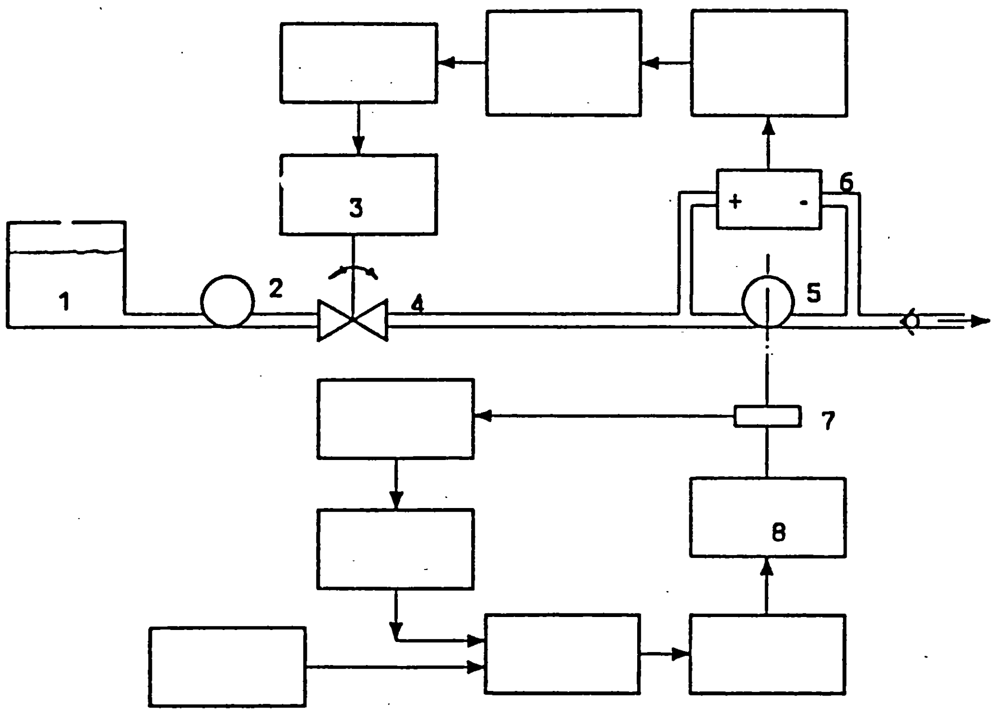
Schematic diagram for a closed pesticide metering system

1- water tank	**2- water pump**
3- injection point	**4- booms**
5- pesticide container	**6- pesticide pump**
7- control console	**8- laser system**

Water is drawn from a 2250-litre tank by a centrifugal pump (Hypro 9202) and delivered through a flow meter (Flowtrak F784C). The pesticide is withdrawn from a returnable container (FMC U-turn) by an injection pump (Raven SCS 700). The water and pesticide pass through an inline mixer and half goes to the booms, the remainder to an optical detection system. A laser beam (Aerotech LSR 5P He-Ne laser) is passed through the solution and the remaining beam detected by a photodetector (UDT-455).

Reference: Budwig et al (1988)

A.22



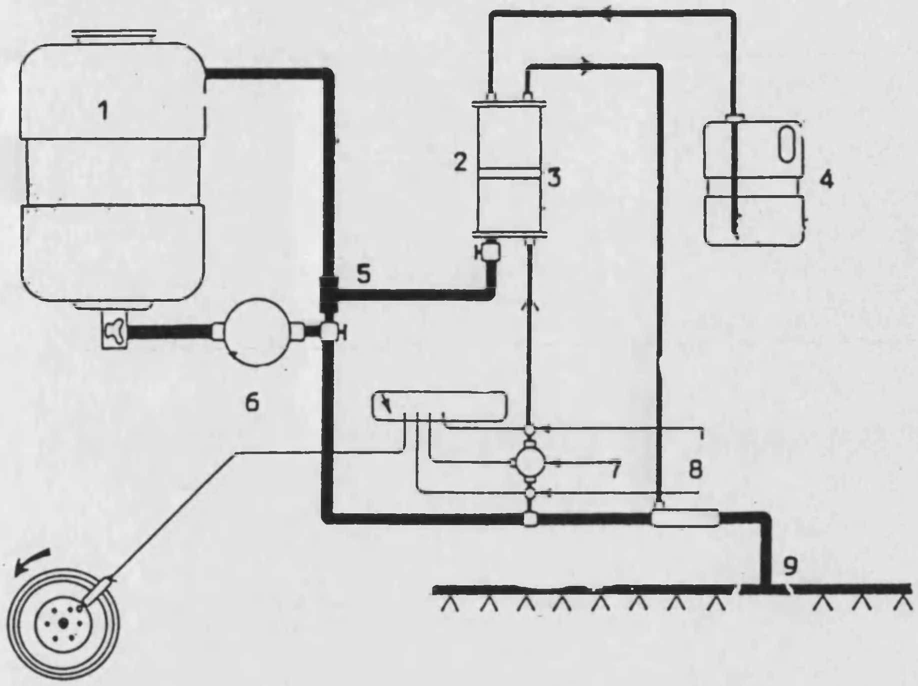
Block diagram for the flow rate control system for direct injection

1- pesticide tank **2- pesticide pump**
3- stepping motor **4- needle valve**
5- metering pump
6- differential pressure transducer
7- disc **8- d.c.motor**

A control system was designed to ensure accurate injection. A vane-type fuel pump (12-802 Holley) was used as the metering pump. The metering pump motor was used to measure the flow rate and to control the differential pressure across the metering pump. A needle valve was used to control the flow to the metering pump. An electro-mechanical feedback technique was used to keep the differential pressure to zero.

Reference: Chi et al (1988)

A.23



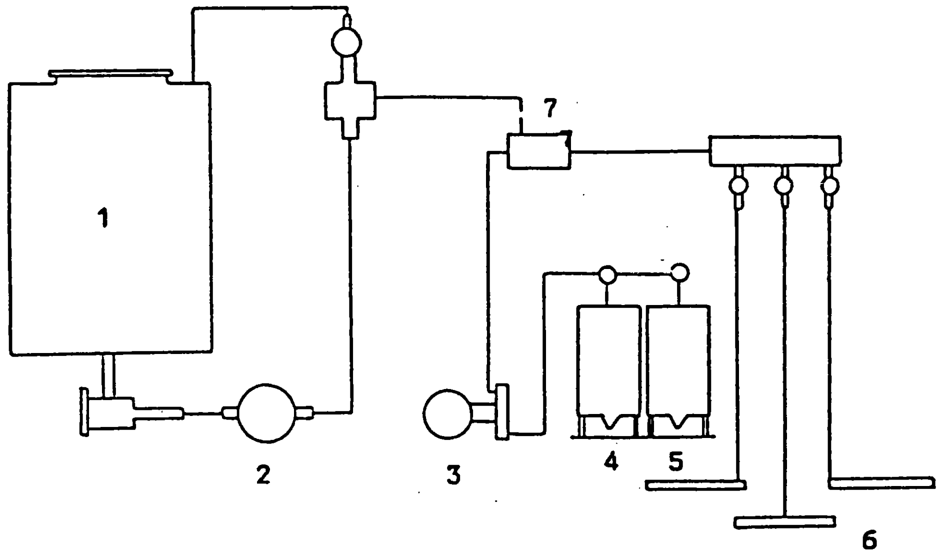
The Silsoe Research injection system

1- water tank **2- cylinder** **3- piston**
4- pesticide container **5- venturi**
6- water pump **7- metering pump**
8- pressure sensors **9- boom**

Pesticide is removed from the original container by suction created in the cylinder due to water being withdrawn from one side of the piston. A venturi situated in the sprayer return line, between the water pump and the water tank, creates the suction. This action is similar to the action of a hyperdermic syringe. The piston direction can be reversed within the cylinder, thus pushing out the pesticide into the mixing chamber situated in the main water line. The piston is pushed by means of a metering pump which withdraws water from the main water line.

Reference: Frost (1988)

<u>A.24</u>

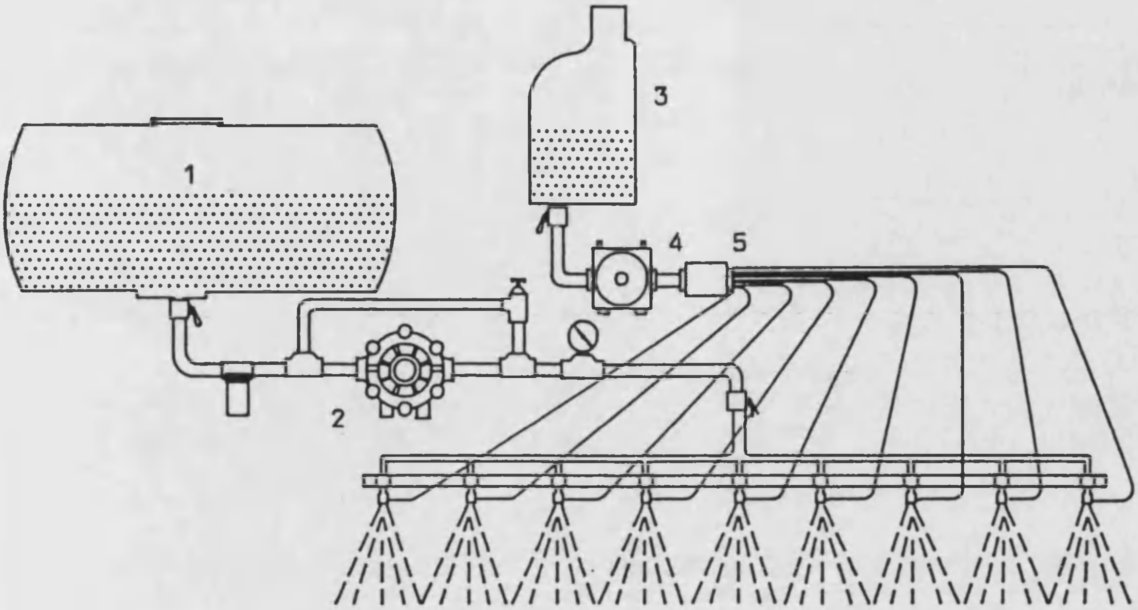


The AgriFutura Dose 2000 injection system

1- water tank **2- water pump**
3- injection pump **4- pesticide container**
5- water container **6- booms**
7- mixing chamber

Pesticide is withdrawn from the 30-litre container by means of a probe connected via a pipe to an injection pump. The injection pump (Wallace and Tiernan G50v) comprises an alumina ceramic piston in a stainless steel cylinder.
The piston stroke length is controlled by means of a stepper motor, thus altering dose rate. The pesticide is injected into the mixing chamber, situated between the pressure regulating valve and the boom control valves, where it joins with water from the sprayer water pump. An electronic controller allows dose rate adjustments on the move.
Reference: Wallenas (1988)

A.25



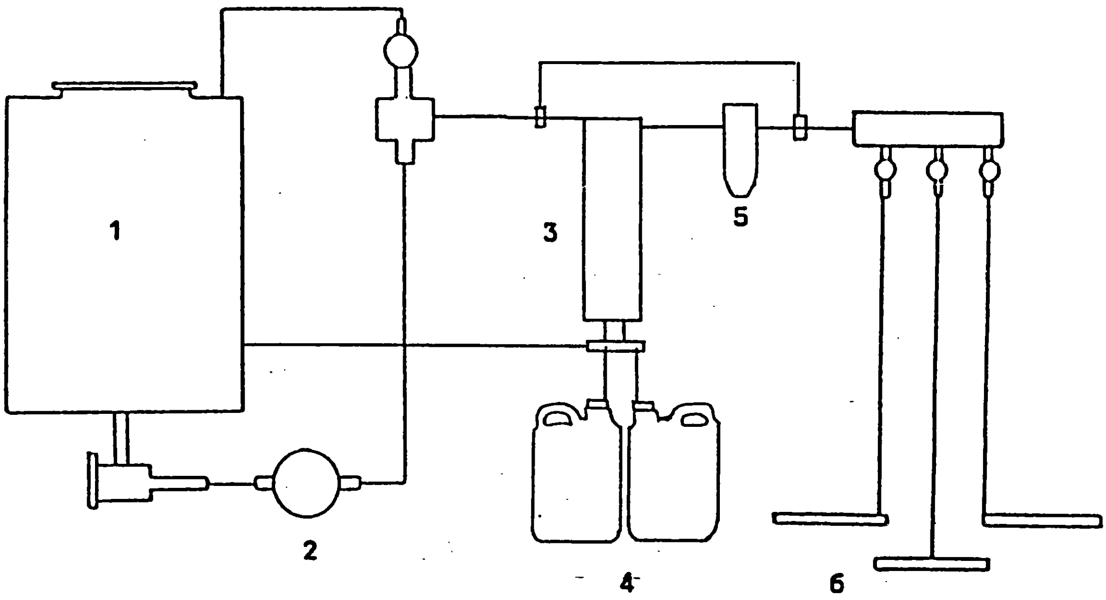
A schematic diagram of an experimental injection sprayer employing direct injection at the individual nozzles

1- water tank **2- water pump**
3- pesticide container **4- pesticide pump**
5- manifold **6- nozzles**

A laboratory injection system was developed to compare injecting tracer into the diluent stream at three points on a sprayer. Tracer was injected immediately upstream of the pump at low pressure, and at high pressure immediately downstream of the pump and at the individual nozzles. The above diagram shows the latter trial. The pesticide pump for the low pressure trial was a peristaltic pump driven by a stepper motor. Two piston pumps were used for the other trials, Scienco Inc. and FMI Inc. Water was pumped by a roller pump driven by an electric motor. A pesticide mimic, Pottassium bromide, was injected into the side of Spraying Systems 8004 nozzles.

Reference: Tompkins et al (1988)

<u>**A.26**</u>



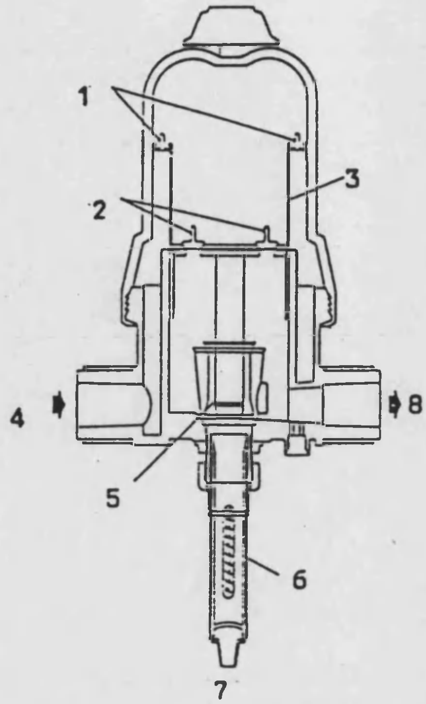
The MSR Ciba-Geigy Agroinject

1- water tank **2- water pump**
3- injection pump **4- pesticide containers**
5- mixing chamber **6- booms**

Water is used to drive the MSR injection pump. Connected to the reciprocating piston of the pump are four smaller piston pumps, each connected via suction pipes to the original pesticide containers. The dose rate is set by an adjustable scale which alters the piston stroke length. The pesticide joins the water in the injection pump and is further mixed in the mixing chamber. Individual containers may be switched on or off by means of solenoid valves.

Reference: David (1989)

A.27



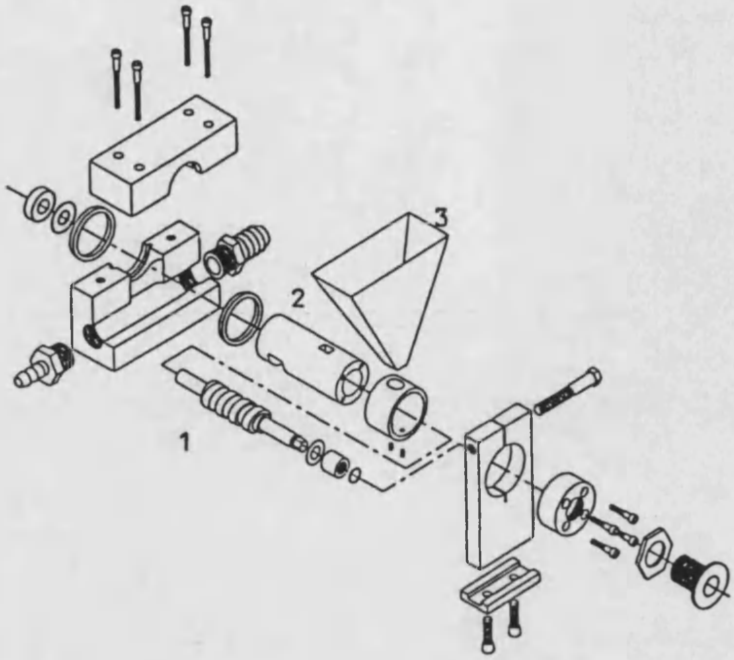
The Tecnoma hydraulic proportional feeder

1- valves A	**2- valves B**
3- piston A	**4- water in**
5- injector piston	**6- dose adjustment**
7- pesticide connector	**8- pesticide/water out**

The pesticide injection pump is the Dosatron proportional inline injector. The water driven pump is situated between the pressure regulator and the boom control valves of the sprayer. Water enters the lower chamber and passes through the valves. Pesticide is withdrawn from the original container, via a suction pipe, to the connector of the injector piston. The pesticide mixes with the water as it passes through the pump. The dose rate is adjusted manually by adjusting the dosing housing which in turn alters the stroke length of the injection piston.

Reference: Doser (1989)

A.28



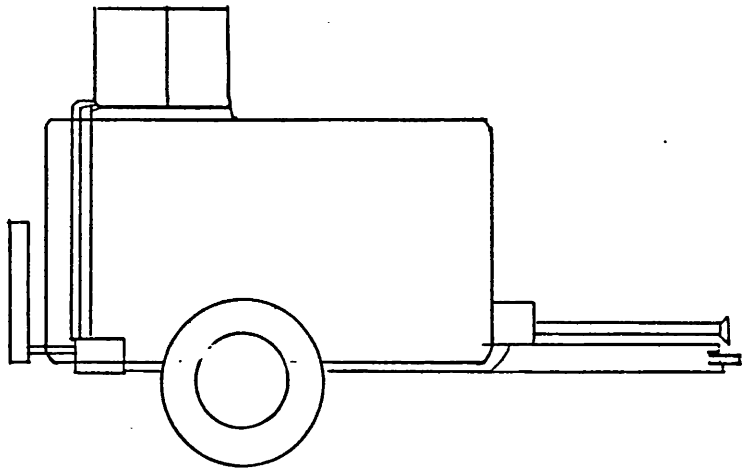
Exploded view of the metering/crushing unit

1- metering/crushing screw   2- sleeve   3- hopper

A laboratory apparatus was designed to crush and meter dry flowable pesticides into water. A Hypro D19 twin diaphragm pump, driven by an electric motor, was used for the trials. An accumulator was installed in line to eliminate pulsations caused by the pump. The crushing unit was situated between the water tank and the pulsation dampener, on the suction side of the water pump. Tests were carried out to indicate the time required to disperse the powders.

Reference: Hart and Gaultney (1989)

A.29

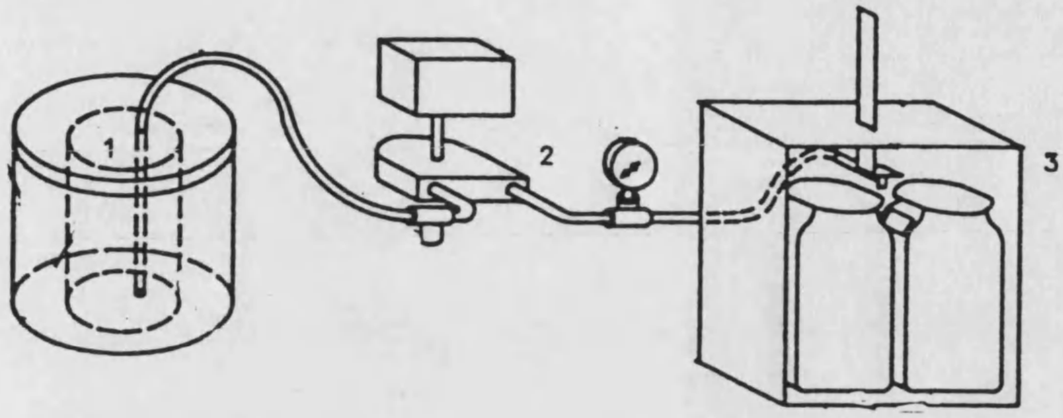


Lindus injection system

The pesticide is decanted from the original containers into two 50-litre tanks on top of the sprayer water tank. The pesticide feeds by gravity into the rotary / reciprocating piston pumps; each pump comprises an eight millimetre diameter ceramic piston. One 12-volt electric motor drives two pump-heads, a pump head on each end of the motor. A smaller single pump is used for lower application rates. The pesticide is injected after the water pump and before the booms. An electronic controller allows dose adjustments on the move.

Reference: Lindus (1989)

A.30



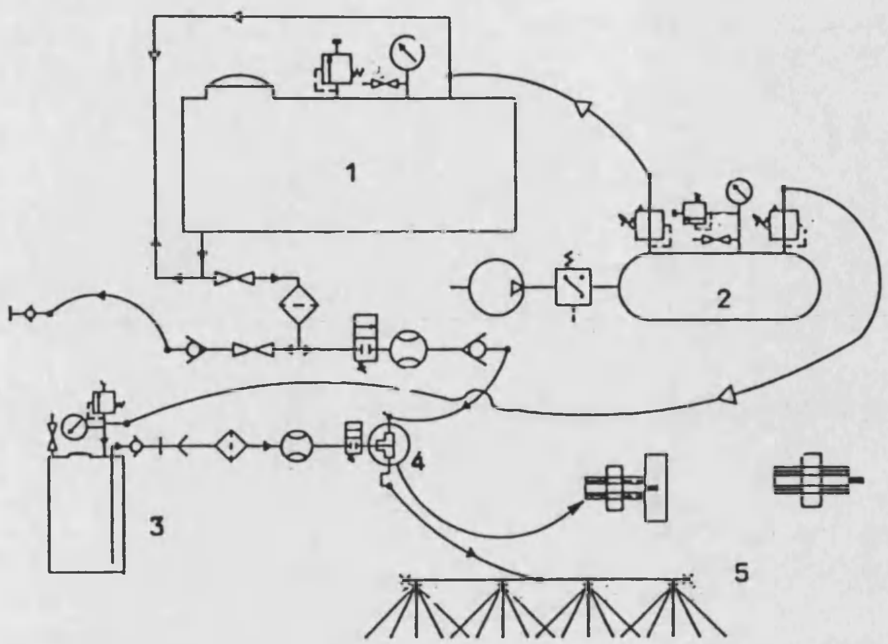
Laboratory layout for injection pump testing

1- pesticide container 2- pesticide pump
3- calibration jars

Two peristaltic pumps were tested for the accuracy with three pesticides at three temperatures. A Masterflex 7018-40 and a Randolph 610 peristaltic pump were connected to a container of pesticide. The container was held at the required temperature by means of a water jacket. The pumped pesticide was collected in calibrated jars.

Reference: Way et al (1989)

A.31



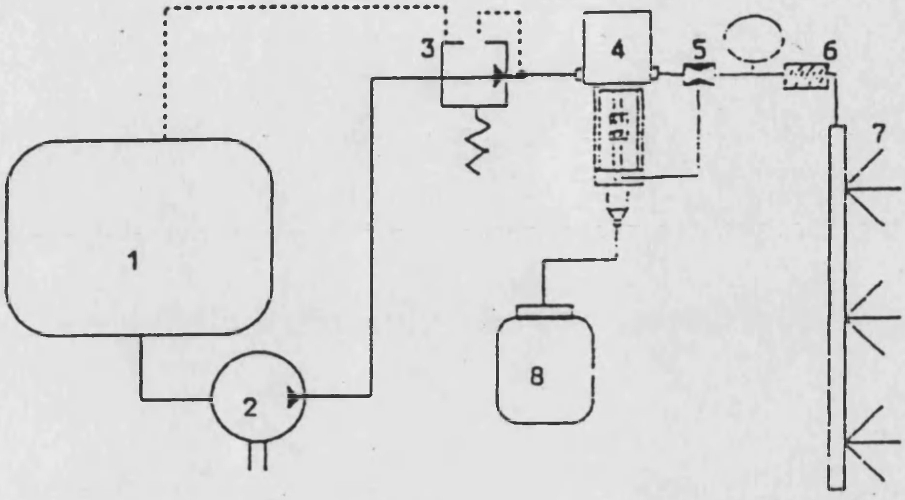
Schematic diagram of the compressed air sprayer

1- water tank **2- air compressor and tank**
3- pesticide tank **4-injection point and mixing chamber**
5- booms

Compressed air is supplied by the compressor and stored in the tank. Regulated air is supplied to the water and pesticide tanks under the desired pressures. Note that this sprayer does not have a water pump. The injection device comprises a three millimetre hole with an adjustable needle valve. The water flow is controlled by the air pressure and the nozzle hole size. The pesticide flow is controlled by a combination of air pressure, the needle valve and the size of the injection device. The injection point and mixing chamber are situated just before the booms.

Reference: Ghate and Phatak (1990)

A.32



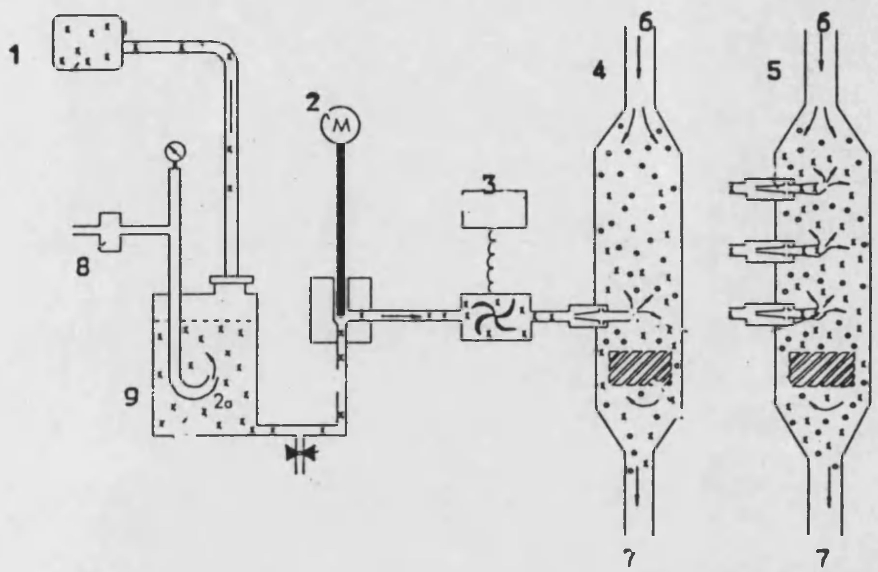
Automatic dosing unit

1- water tank	**2- water pump**
3- pressure regulator	**4- injection pump**
5- venturi	**6- mixer**
7- booms	**8- pesticide container**

Pesticide is removed from the container by means of a suction pipe connected to the dosing pump. The dosing pump is driven by water passing through it and is connected between the water pressure regulator and the booms. The pesticide is pumped into the water line, assisted by the action of the venturi.

Reference: Spugnoli and Vieri (1990)

A.33



Schonlebers 'DOS-INTRO' injection system

1- pesticide container   2- flow rate adjuster
3- flow meter
4- injection point/mixing chamber-1 injector
5- injection point/mixing chamber-3 injectors
6- water in   7- water/pesticide out
8- air compressor   9- pesticide tank

Pesticide is withdrawn from the original container into the pesticide tank. The tractor's air compressor (fitted for tractor/trailer brakes) provides the compressed air to pressurise the pesticide to 4-5 bar. The pesticide passes through a flow meter which will ultimately be connected to an on-board controller which will then adjust the flow rate valve. The pesticide is injected into the mixing chamber where it joins with water from the pressure regulator.
Reference: Preusse (1991)

APPENDIX B

THE COMPONENTS OF AN INJECTION SYSTEM

APPENDIX B : THE AGRIFUTURA DOSE 2000

B.1 Description of the injection pump

The Wallace and Tiernan G50v piston pump (Figure B.1) comprises a stainless steel head, and a ceramic piston and PTFE seals. The pump is driven via the tractor pto input at 1000rpm. The pump incorporates a stepless variable stroke mechanism. The eccentric movement may be adjusted between zero and maximum (0-15mm stroke length) whilst the pump is running, thereby altering the length of stroke imparted to the piston with the output of the pump similarly adjusted. This is effected by means of an electric stepper motor.

Injection pump specification

Make:	Wallace and Tiernan
Model:	G50v
Power:	0.35 KW
RPM:	1000 via tractor pto or hydraulic motor
Head:	316 stainless steel
Valve balls and seats:	316 stainless steel
Piston:	high alumina ceramic
Gland packing:	PTFE
Drive end:	0-15 mm stroke, stepper motor controlled

B.2 Operation of the Pump

The tractor power-take-off (pto) shaft or an hydraulic motor supplies the power required to raise the liquid from suction to delivery pressure. The pump drive converts the rotation of the driving unit into a reciprocating motion of the piston. When the piston is at the front or top dead centre

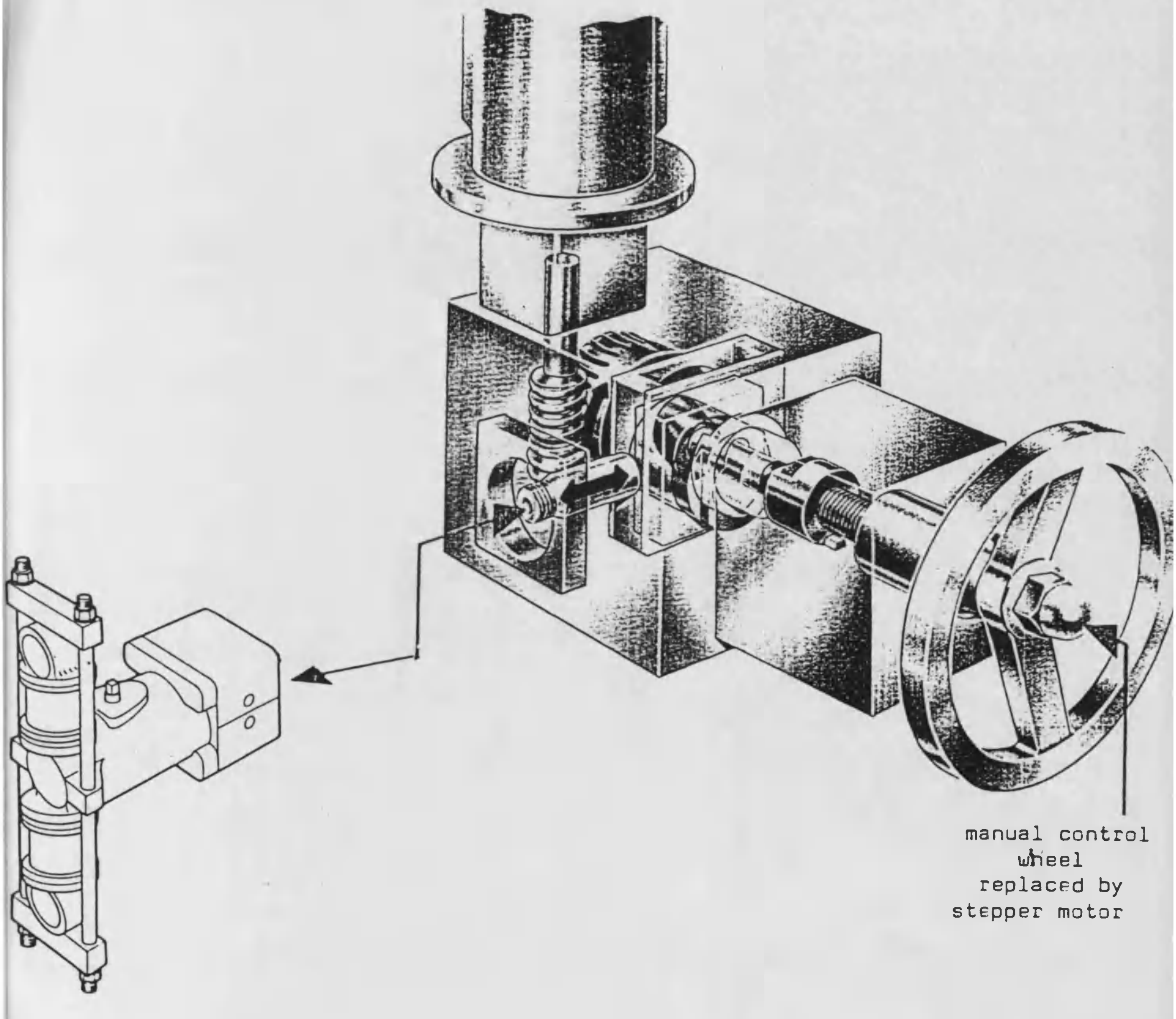


Figure B.1 Wallace and Tiernan injection pump G50v

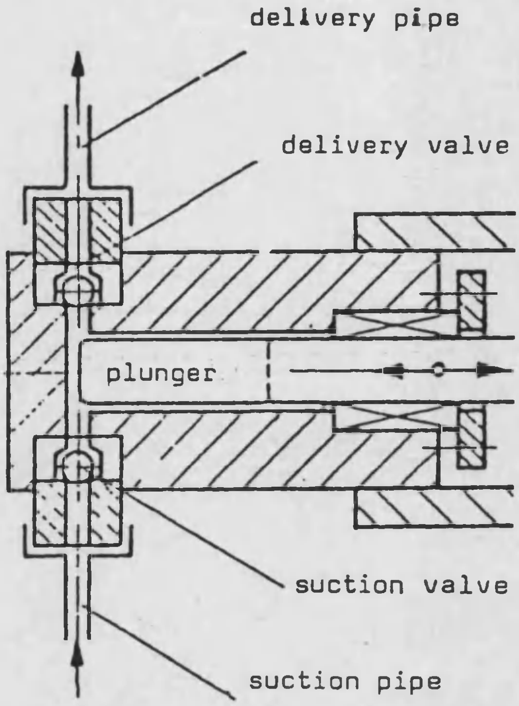


Figure B.2 Cross section of an injection pump head

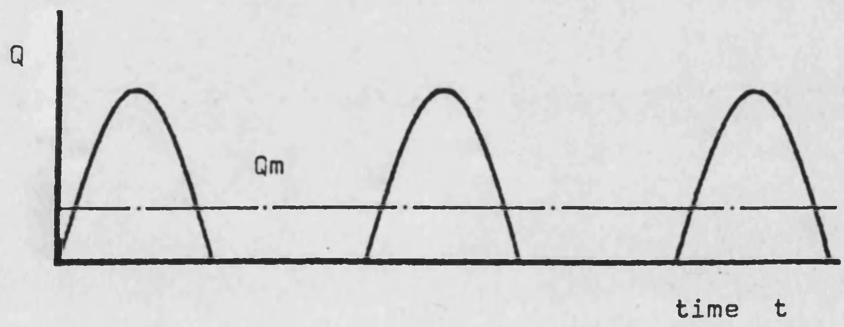


Figure B.3 Delivery from a reciprocating piston pump

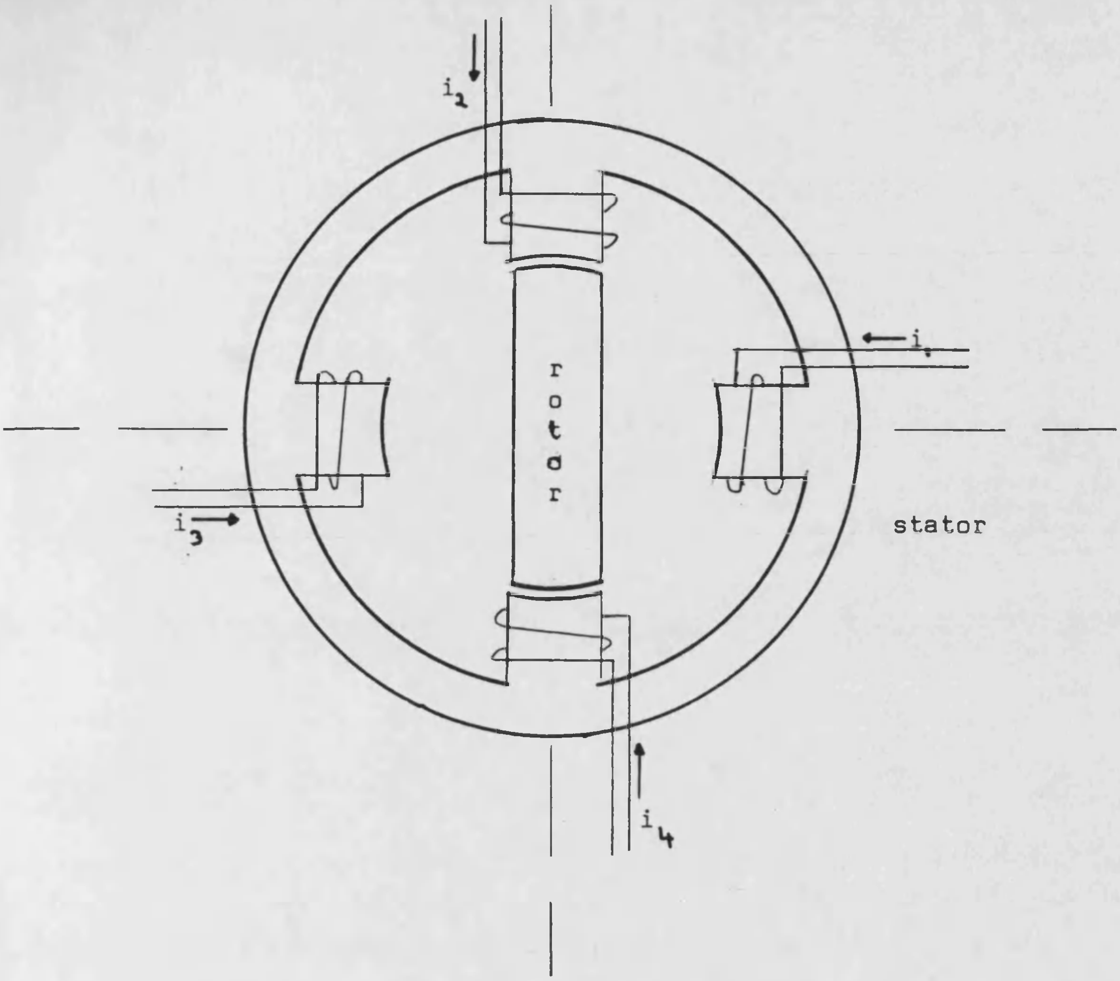


Figure B.4a Stepper motor

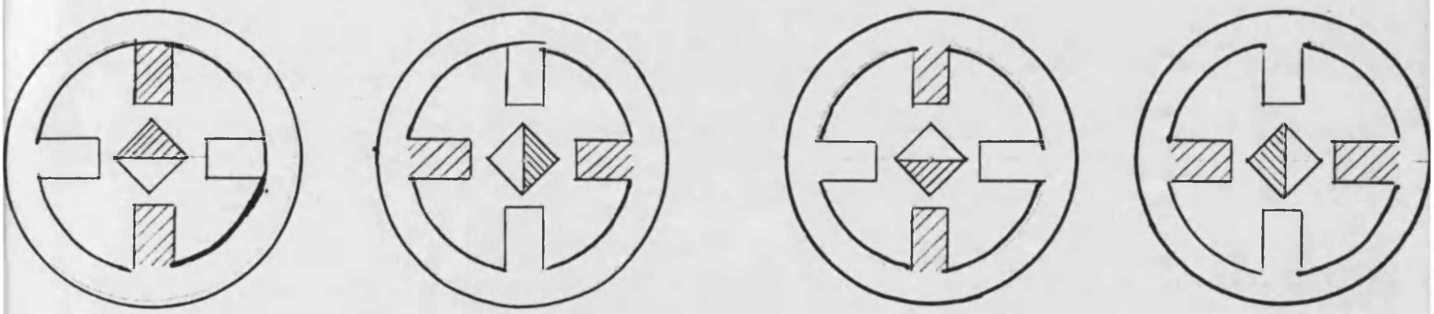


Figure B.4b Stepper motor : principle of operation at 45° increments

(Figure B.2), the suction and delivery valves are closed and the liquid in the pump chamber is at operating pressure (4 bar). Withdrawal of the piston effects the suction stroke during which the volume of the pump chamber is increased in proportion to the piston velocity. At the beginning of the suction stroke, the liquid in the pump chamber is quickly reduced to the pressure in the suction line. It then falls below that pressure, resulting in the suction valve opening. Liquid is sucked into the chamber.

When the piston is at the rear or bottom dead centre, the suction valve closes, forward movement of the piston causes the compression stroke, the liquid pressure rises, lifting the delivery valve off its seat, and pumping the liquid out of the chamber. At the end of the compression stroke the delivery valve closes and the suction stroke begins.

The piston pump produces a pulsating delivery flow. During each stroke the liquid in the pipe will accelerate and then retard again. Figure B.3 shows the delivery. Fortunately, the mixing chamber and sprayer pipeline accommodates the fluctuations and evens out the pulsing effect.

B.3 Operation of the Stepper motor

The stepper motor comprises a number of field windings (stator) and an iron rotor (Figure B.4a). Numerous teeth are cut into the circumference of the stator and the interior of the rotor comprises permanent magnets. When the stator windings are excited by a 12-volt electric current, the rotor rotates towards the excited winding, due to the first law of magnetism (unlike poles attract, like poles repel). Each field winding can be energised in turn, thus the rotor turns step by step, (Figure B.4b). To obtain smaller steps, more stator poles are required.

The stepper motor used to adjust the piston stroke length on the injection pump comprises field windings at 1.8^{o} intervals. An electronic control box allows each field winding to be energised in sequence; there are 200 field windings and so 200 steps at 1.8^{o} result in a complete turn of 360^{o} 10 full turns give 2000 steps from zero to the maximum stroke length of 15mm. 2000 steps also give the name to the system, the Dose 2000, see Tables B.2 and B.3.

B.4 Operation of the variable stroke mechanism to adjust dose rate

The variable stroke mechanism of the injection pump is traditionally fitted with a hand wheel for making manual adjustments to the piston stroke length. The hand wheel is removed and the stepper motor fitted in its place. As the stepper motor turns step by step (at 1.8^{o} intervals) it alters the eccentric unit (Figures B.5 and B.6), thus adjusting the stroke length of the piston. The eccentric unit is located inside the piston driving shaft which rotates axially due to the tractor pto input and

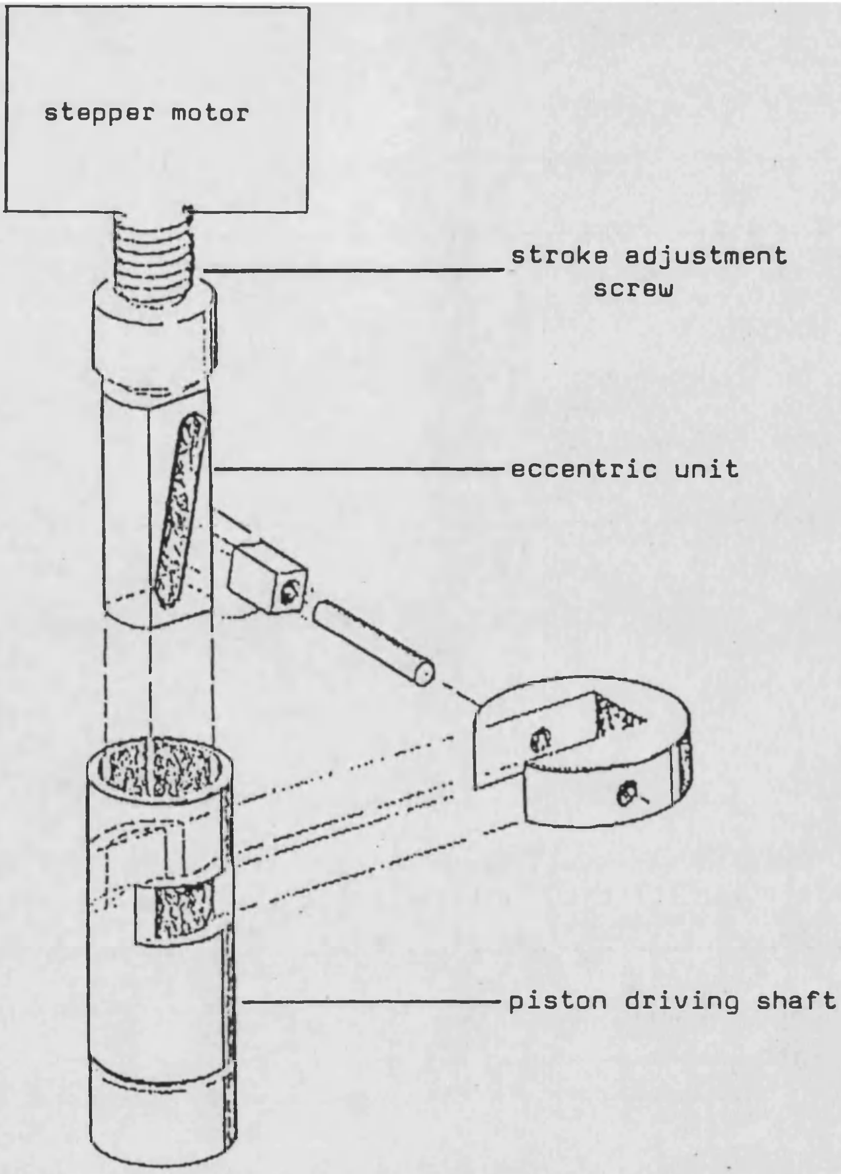


Figure B.5 Eccentric unit on the piston pump drive

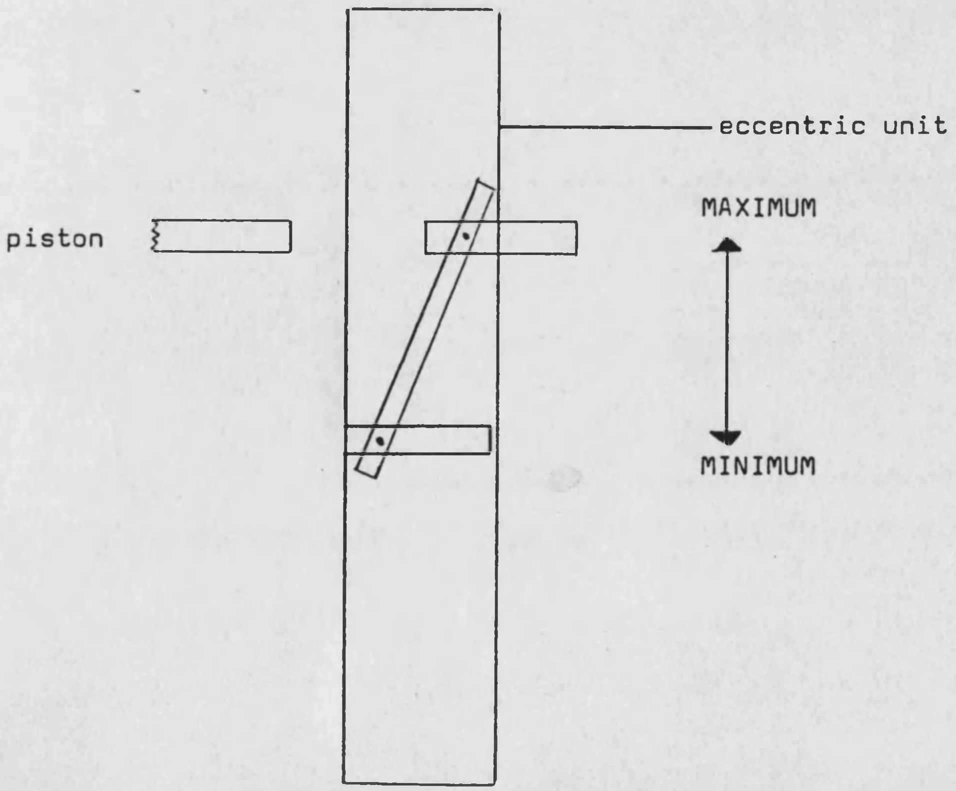


Figure B.6 Eccentric unit : schematic

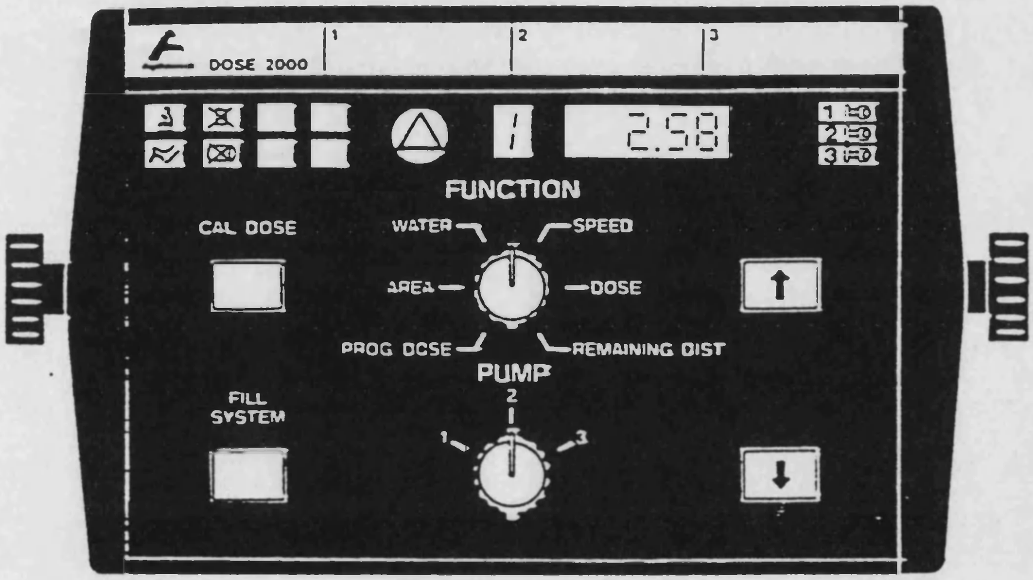


Figure B.7 The in-cab controller

Table B.1 Machine specifications

A number of parameters are unique to each sprayer. These are set on the in-cab controller by placing a magnetic card on the controller before switching the system on. The specification number is displayed; to change a value the operator presses the CAL button and uses the increase/decrease buttons.

3.9	1	circumference of the jockey wheel
24	2	number of pulses per rev of the jockey wheel
49	3	pulses per litre of water flow sensor
40	4.1	constant used in Fill System equation pump1
40	4.2	constant used in Fill System equation pump2
-	4.3	constant used in Fill System equation pump3
249.1	5.1	constant in flow vs step equation pump1
277.4	5.2	constant in flow vs step equation pump2
-	5.3	constant in flow vs step equation pump3
180	6.1	volume in ml of pesticide pipe 1
250	6.2	volume in ml of pesticide pipe 2
-	6.3	volume in ml of pesticide pipe 3
78	7.1	sync step on pump 1
53	7.2	sync step on pump 2
-	7.3	sync step on pump 3
2000	8	max step number of any pump
20	9	total sprayer width (metres)
40	10	total number of nozzles
10	11.1	number of nozzles on boom part 1 (left)
10	11.2	number of nozzles on boom part 2
10	11.3	number of nozzles on boom part 3
10	11.4	number of nozzles on boom part 4
-	11.5	number of nozzles on boom part 5
-	11.6	number of nozzles on boom part 6
2	12	number of injection pumps
927	13.1	offset step in flow vs step equation pump1
969	13.2	offset step in flow vs step equation pump2
-	13.3	offset step in flow vs step equation pump3
30	14	K value for mean speed and mean water flow
11.3	15.1	volume of boom pipe (l) to first nozzle
26.3	15.2	volume of boom pipe (l) to last nozzle
1500	16	tank volume (l)
15	17	% water remaining in tank when alarm sounds
400	18	speed of stepper motors in steps/second

MACHINE: Hardi 1500 20m
DATE: 1-05-89

slides up and down due to the stroke adjustment thus altering the piston stroke length from minimum to maximum.

B.5The in-cab controller

The controller (Figure B.7) is connected to the tractor 12-volt supply. The machine specification is inserted into the micro-processor by using a magnetic card. Table B.1 gives an example of the Hardi specification used in the trials.

The various functions of the control box are:

i) **injection pumps**

The controller allows the operator to select one to three injection pumps, either individually or in any combination. Each pump is connected to a pesticide container, so pumps 1, 2 and 3 are connected to containers A, B and C. By turning the switch marked pump to position 1 and having the function switch at the required dose level, the injection pump will operate when the sprayer travels along the field pumping water. If the water flow ceases, e.g at the headland turn, the water flow sensor sends a signal to inform the controller and this in turn switches off the injection pump.

ii) **the function switch has a number of positions:**

a) programme dose

the operator selects the dose level required from the pesticide label or the crop walkers' recommendation. By pressing the increase/decrease arrow buttons the operator can select the exact dose required. The maximum dose level required can be set when the function switch is at Dose level 4. Any change in dose level, e.g. to operate the pump at a lower rate for a lower infestation can be made by changing the function button to Dose level 3, 2 or 1 and selecting a lower dose rate via programme dose.

b) area

The area covered whilst the sprayer is in operation is shown on the display.

c) water

The current water flow is shown on the display and is a useful aid to double check the application rate.

d) speed

The current speed is shown on the display.

e) dose level

Four preset dose levels may be set according to the requirements under programme dose. The dose levels can be changed whilst on the move by pressing the increase/decrease arrow buttons.

f) remaining distance

The remaining distance feature allows the operator to see in the display the distance he has to travel after changing from pesticide to rinsing water to decontaminate the sprayer. The distance is based upon the pipe volume from the container valve to the first nozzle and the dose rate, Figure B.10.

iii) **The Cal. Dose button**

A calibration factor may be entered into the controller to take into account variations in pesticide viscosity. The display shows the number; by pressing the increase/decrease arrow buttons, the Cal.Dose may be adjusted.

iv) **The Fill System button**

This button is used to fill the injection system with water or pesticide. When the button is pressed, the injection pump starts pumping liquid from the container to the injector situated in the side of the mixing chamber. A warning light in the panel operates during this period. At the beginning of a field, the operator presses this button and fills the system to the mixing chamber; pressing the button again with the water flow switched on, pumps pesticide into the water until the pesticide reaches the first nozzle. A warning buzzer sounds, the operator can then drive away, resulting in the w-shape pattern described in the field trials (section 4.8). Remaining at the headland for a few seconds more means the water continues to flow out, resulting in pesticide reaching the last nozzle. When a second buzzer sounds the driver can set off, resulting in the whole boom width spraying correctly.

v) **Alarm lights**

A number of alarm indicator lights are fitted to alert the operator when pesticide or water is running low, a hose

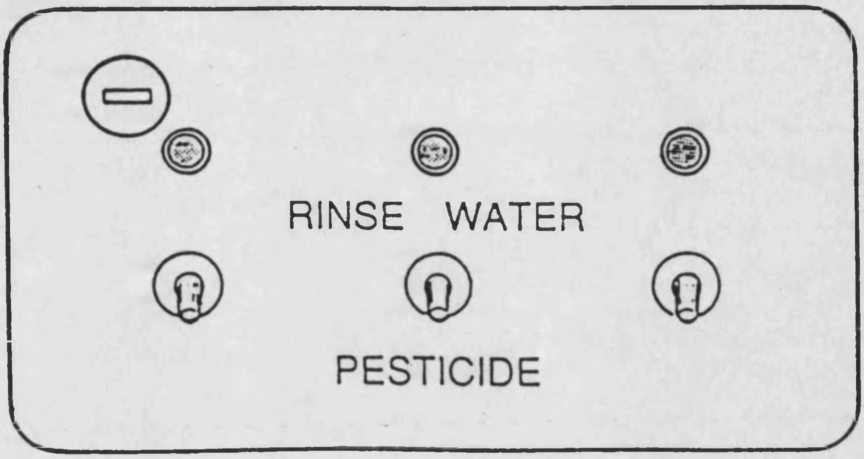


Figure 8.8 The remote control unit

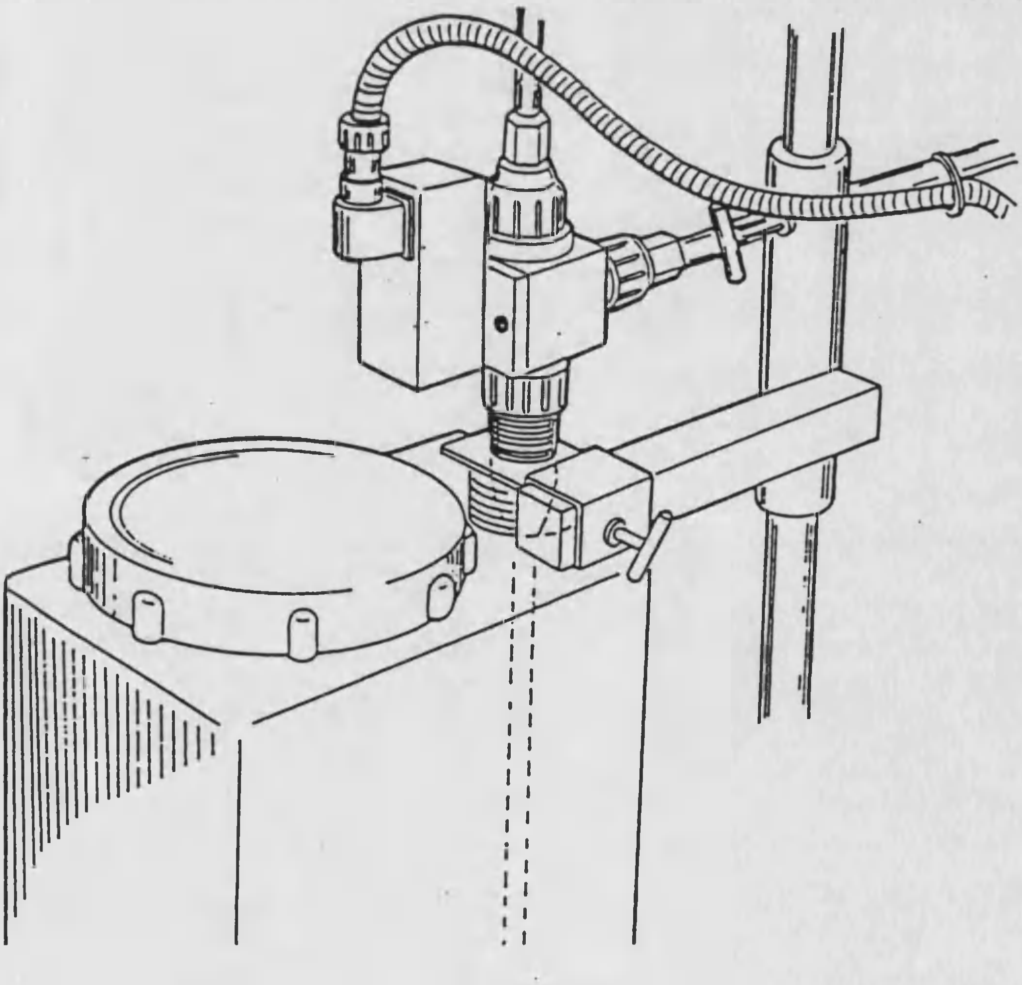
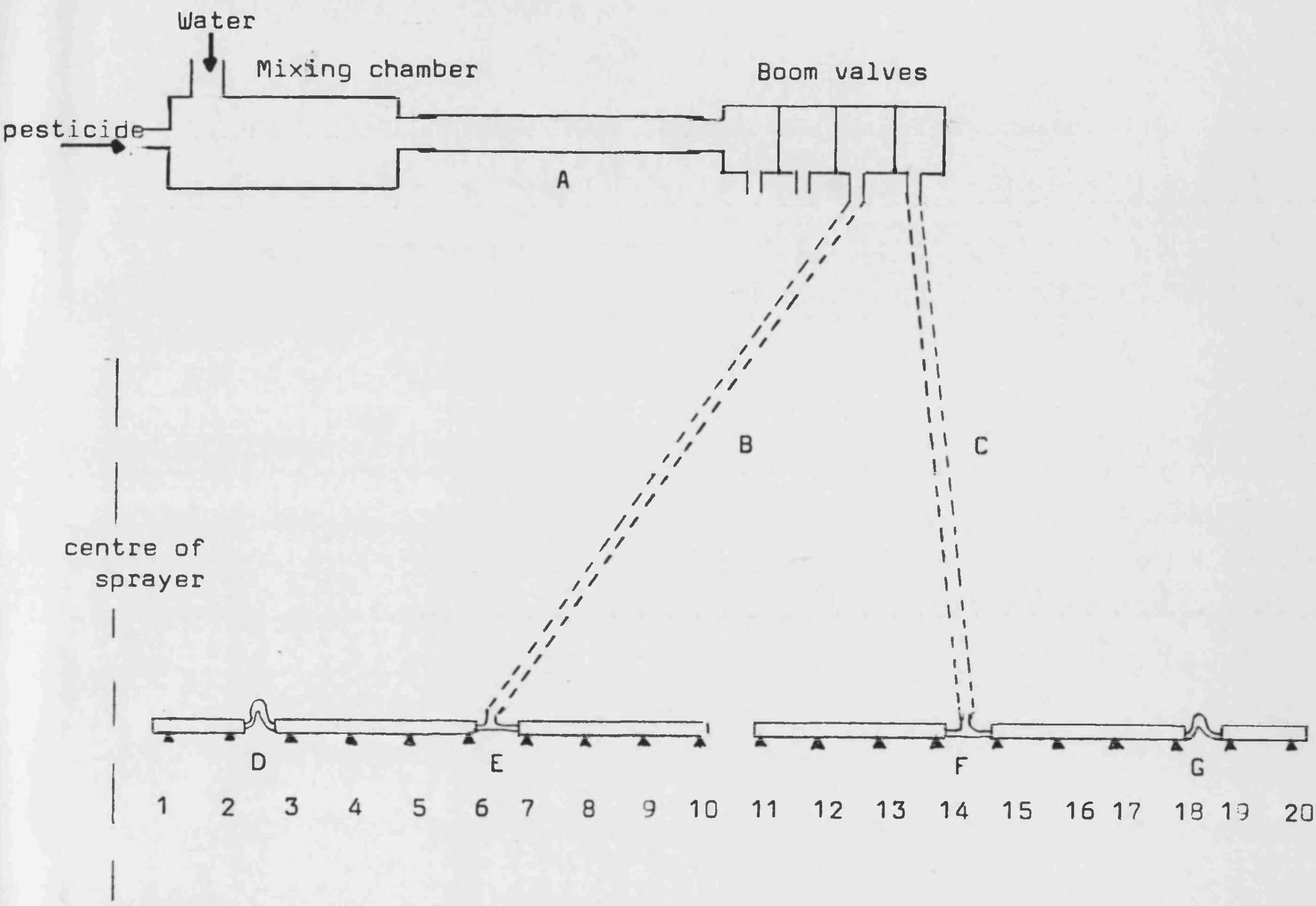


Figure 8.9 The solenoid operated valve and container

Figure B.10 Boom pipe layout and nozzle designation



Pipe sizes (mm)

Pipe	Length	Diameter outside	Diameter inside
A	900	35	31.25
B	8900	28	25
C	12775	28	25
D	800	21	18
E	400	21	18
F	750	21	18
G	750	21	18

leak, speed errors and system faults. The lights are used in conjunction with a warning buzzer.

B.6The remote control unit

This unit allows the operator to switch from pesticide to rinse water. There is a switch for each container and a red light glows when pesticide is switched on (Figure B.8). A solenoid operates the valve at the container (Figure B.9).

Table B.2 Dose rates possible with the standard pump head

Boom Width	Speed km/h	Min. Dose Rate l/ha	Max. Dose Rate l/ha
	4	2.79	32.00
	6	1.86	21.33
12	8	1.40	16.00
	10	1.12	12.80
	12	0.93	10.67
	14	0.80	9.14
	16	0.70	8.00
	4	1.86	21.33
	6	1.24	14.22
18	8	0.93	10.67
	10	0.74	8.53
	12	0.62	7.11
	14	0.53	6.10
	16	0.47	5.33
	4	1.40	16.00
	6	0.93	10.67
24	8	0.70	8.00
	10	0.56	6.40
	12	0.47	5.33
	14	0.40	4.57
	16	0.35	4.00

Table B.3 Dose rates possible with the smaller pump head

Boom Width	Speed km/h	Min. Dose Rate l/ha	Max. Dose Rate l/ha
	4	0.60	6.00
	6	0.40	4.00
12	8	0.30	3.00
	10	0.24	2.40
	12	0.20	2.00
	14	0.17	1.71
	16	0.15	1.50
	4	0.40	4.00
	6	0.27	2.67
18	8	0.20	2.00
	10	0.16	1.60
	12	0.13	1.33
	14	0.11	1.14
	16	0.10	1.00
	4	0.30	3.00
	6	0.20	2.00
24	8	0.15	1.50
	10	0.12	1.20
	12	0.10	1.00
	14	0.09	0.86
	16	0.08	0.75

APPENDIX C

LABORATORY AND FIELD TEST RESULTS

Table C.1 Ambient air temperatures recorded at the Royal Agricultural College, Cirencester

	Temperature min.	^{o}C max.
January	1.30	7.80
February	0.91	6.94
March	2.64	10.55
April	3.70	13.17
May	6.83	17.90
June	10.16	20.94
July	12.29	24.05
August	12.01	23.29
September	10.18	19.74
October	7.19	15.62
November	4.09	10.75
December	3.19	8.66

Ten year average

Table C.2 Linearity of pump output - belt drive

Summary of Tests 1, 2 and 3

Step No.	Pump Output (litres/hour) Test 1	Test 2	Test 3	Time (mins.)
200	10.28	10.10	8.77	40
400	25.19	25.51	15.73	20
600	40.79	40.00	31.61	10
800	55.18	54.43	41.86	8
1000	72.49	67.88	59.74	6
1200	86.93	81.65	72.00	5
1400	106.24	95.83	89.48	5
1600	122.98	110.05	90.85	5
1800	135.24	127.36	93.64	5
2000	146.57	123.11	122.52	5

Table C.3 Linearity of pump output - belt drive

Summary of Regression Analysis for Tests 1, 2 and 3

	intersection y axis a	inclination coefficient b
Test 1	-5.70	7.80
Test 2	-3.31	7.15
Test 3 original	-4.70	6.17
revised	-9.04	6.83

where $a = \dfrac{\sum y - b \times \sum x}{n}$

$$b = \frac{n \times \sum xy - \sum x \times \sum y}{n \times \sum x^2 - (\sum x)^2}$$

Table C.4 Linearity of pump output - hydraulic motor

Summary of Tests 1, 2 and 3

Step No.	Pump Output (litres/hour) Test A	Test B	Test C	Time (mins.)
200	11.09	7.10	2.41	40
400	24.10	19.81	5.09	20
600	37.46	32.49	7.69	10
800	51.24	46.34	10.34	8
1000	64.60	59.67	13.01	6
1200	77.97	73.31	15.63	5
1400	91.19	86.62	18.22	5
1600	104.31	99.93	20.83	5
1800	117.71	113.25	23.40	5

?

Table C.5 Linearity of pump output - hydraulic motor

Summary of Regression Analysis for Tests 1, 2 and 3

	intersection y axis a	inclination coefficient b
Test A	-2.36	6.67
Test B	-6.84	6.66
Test C	-0.16	0.01

where $a = \dfrac{\sum y - b \times \sum x}{n}$

$$b = \frac{n \times \sum xy - \sum x \times \sum y}{n \times \sum x^2 - (\sum x)^2}$$

Table C.6 Test No.1 Uniformity of concentration between nozzles during constant injection at 2.5 l and 5.0 l in 100 l/ha

	FIRST NOZZLE			LAST NOZZLE		
Time Seconds	Jar No.	Meter Reading 2.5	Meter Reading 5.0	Jar No.	Meter Reading 2.5	Meter Reading 5.0
0	1	0.0	0.0	50	0.0	0.0
5	2	0.0	0.0	51	0.0	0.0
10	3	0.0	0.0	52	0.0	0.0
15	4	0.0	0.0	53	0.0	0.0
20	5	5.6	0.0	54	0.0	0.0
25	6	9.8	15.0	55	0.0	0.0
30	7	9.8	22.0	56	0.0	0.0
35	8	10.1	22.2	57	0.0	0.0
40	9	10.1	22.4	58	0.0	0.0
45	10	10.2	22.8	59	0.0	0.0
50	11	10.3	22.9	60	5.5	0.0
55	12	10.3	22.9	61	9.9	0.0
60	13	10.5	23.1	62	10.0	0.0
65	14	10.5	22.9	63	10.1	13.5
70	15	11.3	22.9	64	10.5	21.0
75	16	11.0	22.8	65	11.0	22.5
80	17	11.0	22.7	66	11.1	22.8
90	18	10.9	22.8	67	11.0	22.9
100	19	10.9	22.6	68	11.5	23.2
110	20	10.9	22.8	69	11.4	23.1
120	21	10.9	22.9	70	11.2	23.0
130	22	11.0	22.9	71	11.0	22.8
140	23	11.5	22.7	72	10.8	22.5
150	24	11.4	22.6	73	10.9	22.6
160	25	11.4	22.6	74	10.8	22.5
170	26	11.2	22.9	75	11.0	22.8
180	27	11.1	22.9	76	11.3	22.8
190	28	11.3	23.1	77	11.0	23.1
200	29	11.1	22.6	78	11.2	22.6
205	30	11.2	22.7	79	11.0	22.7
210	31	10.9	22.6	80	11.0	22.6
215	32	10.9	22.7	81	10.8	22.6
220	33	6.7	12.0	82	10.8	22.9
225	34	0.0	2.5	83	11.0	22.8
230	35	0.0	0.0	84	10.9	22.4
235	36	0.0	0.0	85	10.8	22.6
240	37	0.0	0.0	86	11.0	22.8
245	38	0.0	0.0	87	10.8	22.6
250	39	0.0	0.0	88	5.0	22.3
255	40	0.0	0.0	89	0.0	22.4
260	41	0.0	0.0	90	0.0	3.0
265	42	0.0	0.0	91	0.0	0.0
270	43	0.0	0.0	92	0.0	0.0
275	44	0.0	0.0	93	0.0	0.0
280	45	0.0	0.0	94	0.0	0.0

Table C.7 Test No.2 Uniformity of mixture concentration as a function of time

Test No.3 Spot spraying delay time or transient time

2.5 l and 5.0 l in 100 l/ha

Time Seconds	Jar No.	Meter Reading 2.5l	Meter Reading 5.0l
0	1	0.0	0.0
5	2	0.0	0.0
10	3	0.0	0.0
15	4	0.0	0.0
20	5	5.8	0.0
25	6	9.4	14.4
30	7	9.7	21.7
35	8	9.7	22.4
40	9	9.7	22.4
45	10	10.3	22.4
50	11	10.3	22.9
55	12	10.2	22.8
60	13	10.5	22.4
65	14	10.6	22.9
70	15	11.4	23.0
75	16	11.0	22.6
80	17	10.8	22.6
90	18	10.8	22.7
100	19	10.6	22.5
110	20	10.6	22.4
120	21	10.7	22.7
130	22	11.0	22.4
140	23	11.8	22.3
150	24	10.3	22.8
160	25	11.4	22.8
170	26	11.2	22.7
180	27	11.1	22.9
185	28	11.8	22.8
190	29	12.1	22.7
195	30	11.2	23.1
200	31	10.9	22.6
205	32	12.3	22.7
210	33	11.1	22.7
215	34	10.9	22.7
220	35	6.4	11.4
225	36	0.0	1.3
230	37	0.0	0.0
235	38	0.0	0.0
240	39	0.0	0.0

Table C.8 Test No.4 Response of the injection system to changes in forward speed at 2.5 l in 100 l/ha

Time Seconds	Jar No.	Meter Reading 2.5	Meter Reading 5.0	Comments
60	1	13.6	28.4	speed:10.8km/hr
65	2	13.6	28.6	
70	3	13.6	28.6	
75	4	13.6	28.6	
80	5	13.6	28.6	
85	6	13.6	29.0	
90	7	13.8	29.0	
95	8	13.8	29.0	
100	9	13.8	29.0	
105	10	14.2	28.8	
110	11	13.6	28.8	
115	12	13.6	29.0	
120	13	13.4	28.8	*change speed
125	14	13.4	29.0	to 9.0km/hr
130	15	13.4	28.8	
135	16	14.0	28.8	
140	17	12.6	28.8	
145	18	11.6	26.4	
150	19	11.2	24.8	
155	20	11.4	24.4	
160	21	11.4	24.4	
165	22	11.4	24.4	
170	23	11.4	24.4	
175	24	11.4	24.4	
180	25	11.4	24.0	*change speed
185	26	11.2	24.2	to 7.2km/hr
190	27	11.4	24.4	
195	28	11.0	24.2	
200	29	11.6	24.2	
205	30	10.2	21.6	
210	31	9.0	19.4	
215	32	8.6	19.0	
220	33	8.8	19.4	
225	34	8.8	19.2	
230	35	9.0	19.0	
235	36	8.8	19.0	
240	37	9.0	19.2	
245	38	9.0	19.4	
250	39	8.6	19.2	
255	40	8.8	19.2	

able C.9 Test No.5 Response of the injection system to changes in dose level 100 l/ha

Time Seconds	Jar No.	Meter Reading	Comments
60	1	22.8	5.0l/ha
65	2	23.0	
70	3	23.2	
75	4	23.2	
80	5	23.8	
85	6	23.4	
90	7	23.8	
95	8	23.4	
100	9	23.4	
105	10	23.4	
110	11	23.2	
115	12	23.2	
120	13	23.6	*change dose
125	14	23.8	to 3.75l/ha
130	15	23.6	
135	16	23.8	
140	17	23.8	
145	18	19.0	
150	19	17.6	
155	20	17.2	
160	21	17.4	
165	22	17.2	
170	23	17.2	
175	24	17.2	
180	25	17.0	*change dose
185	26	17.0	to 2.5l/ha
190	27	17.0	
195	28	17.4	
200	29	17.2	
205	30	13.0	
210	31	11.6	
215	32	11.2	
220	33	11.2	
225	34	11.2	
230	35	11.2	
235	36	11.2	
240	37	11.2	switch off water
245			
250			
255			
260			
265			
270	38	10.8	
275	39	10.8	
280	40	10.8	

Table C.9 Test No.5 Response of the injection system to changes in dose level 100 l/ha

(continued)

Time Seconds	Jar No.	Meter Reading	Comments
285	41	11.0	
290	42	11.2	
295	43	11.0	
300	44	10.8	
305	45	11.0	
310	46	11.0	
315	47	10.6	
320	48	10.6	switch off water
325			
330			
335			
340			
345	49	10.8	
350	50	10.8	
355	51	10.6	
360	52	12.0	
365	53	10.8	
370	54	10.8	
375	55	11.2	
380	56	11.0	
385	57	10.8	

Table C.10 Test No. 6 Response of the injection system to switching the water on and off as at the headland 2.5 l and 5.0 l in 100 l/ha

Time Seconds	Jar No.	Meter Reading 2.5	Meter Reading 5.0	Comments
60	60		23.2	
65	61		23.4	
70	62		23.0	
75	63		23.2	
80	64		23.4	
85	65		23.2	
90	66	11.2	23.4	
95	67	11.2	23.4	
100	68	11.2	23.2	
105	69	11.2	23.0	
110	70	11.2	23.2	
115	71	11.2	23.6	
120	72	11.2	23.6	switch off
125				water
130				
135				
140				
145	73	10.8	23.4	
150	74	10.8	23.4	
155	75	10.8	23.6	
160	76	11.0	29.2	
165	77	11.2	21.2	
170	78	11.0	22.8	
175	79	10.8	23.4	
180	80	11.0	23.6	
185	81	11.0	23.6	
190	82	10.6	23.8	
195	83	10.6	23.4	
200	84	10.8	23.4	switch off
205				water
210				
215				
220				
225	85	10.8	23.8	
230	86	10.6	23.4	
235	87	12.0	23.6	
240	88	10.8	32.2	
245	89	10.8	21.0	
250	90	11.2	22.4	
255	91	11.0	23.2	
260	92	10.8	23.8	
265	93		23.8	
270	94		23.4	
275	95		23.4	
280	96		23.6	
285	97		23.8	

Table C.11 Summary of statistical analysis for boom flow characteristics

Test	mean x	sum x	sum x^2	σ	c v %
test no.1					
first nozzle					
2.5 l	10.80	291.50	3153.53	0.48	4.44
5.0 l	22.73	591.00	13435.42	0.28	1.24
last nozzle					
2.5 l	10.88	293.80	3200.72	0.40	3.68
5.0 l	22.65	588.90	13342.73	0.40	1.77
test no.2&3					
2.5 l	10.81	313.40	3401.06	0.68	6.29
5.0 l	22.68	635.04	14405.58	0.32	1.39
test no.4					
10.0 km/h					
2.5 l	13.66	231.20	3146.08	0.32	2.31
5.0 l	28.80	489.60	14101.04	0.17	0.60
9.0 km/h					
2.5 l	11.36	124.99	1421.00	0.26	2.35
5.0 l	24.35	268.00	6520.20	0.00	0.00
7.2 km/h					
2.5 l	8.84	88.40	781.68	0.17	1.96
5.0 l	19.90	192.00	3686.64	0.14	0.71
test no.5					
2.5 l	11.00	276.00	3049.20	0.30	2.75
3.75 l	17.20	189.40	3261.48	0.20	1.16
5.0 l	23.30	398.40	9338.16	0.30	1.28
test no.6					
2.5 l	11.00	296.80	3264.80	0.28	2.54
5.0 l	23.70	899.00	21390.60	1.79	7.57

σ : standard deviation
c v: coefficient of variation

Table C.12 Comparison of the quantity of wash solution with the solution spots on the TLC plates

Test 1: Flushing solution: water

Beaker No. & Spot No.	B5	B6	B7	B8	B9	B10	B11
Wash sol. (mls)	4700	5200	5700	6200	6700	7200	7700
Isoproturon present	y	y	y	y	y	n	n

Test 2: Flushing solution: 'Supray Spraynett'

Beaker No. & Spot No.	C10	C11	C12	C13	C14	C15	C16
Wash sol. (mls)	2700	3200	3700	4200	4700	5200	5700
Isoproturon present	y	y	y	y	y	n	n

y= yes n= no

Table C.13 Mean pump output for three liquids at three temperatures (litres)

	Temperature °C 8	16	32
Water	5.05	5.05	5.06
Glyphosate	4.80	4.83	4.83
Isoproturon	4.82	4.86	4.90

Table C.14 Density of three liquids at three temperatures (grams/litre)

	Temperature °C 8	16	32
Water	999.85	998.94	995.03
Glyphosate	1172.30	1171.20	1168.60
Isoproturon	1018.50	1020.10	1024.70

Table C.15 Flow-time for three liquids at three temperatures through a DIN beaker (seconds)

	Temperature °C 8	16	32
Water	10.60	10.39	9.74
Glyphosate	34.10	22.04	15.95
Isoproturon	30.58	25.84	22.21

Table C.16 Water soluble bag trials

Trial A - Empty bags and water

Test No.	Stirring time (mins)	water/ bag(l)	filter deposit weight (gms)	visual assess.	comments
A.1	5	0.5	0	3	big lumps
A.2	5	1.0	0	0.5	slight paddle wrap
A.3	2.5	0.5	0	1.0	" " "
A.4	2.5	1.0	0	0.5	" " "
A.5	0	0	0	0	

Test No.	Stirring time (mins)	Time to fill 0.5 l beaker (secs) Beaker No. 1	2	3	4	5	DIN beaker (secs)
A.1	5	8.62	9.35	10.41	11.84	13.78	10.58
A.2	5	8.52	9.45	10.67	11.85	14.09	10.11
A.3	2.5	8.94	9.89	10.66	12.07	14.58	10.58
A.4	2.5	8.89	9.24	10.53	12.20	13.27	10.11
A.5	0	8.15	8.37	9.57	11.35	13.13	10.19

Table C.17 Water soluble bag trials
Trial B - Oxytril bags and water

Test No.	Stirring time (mins)	water/ bag(l)	filter deposit weight (gms)	visual assess.	comments
B.1	5	0.5	0.18	4	big lumps
B.2	5	1.0	0.13	2	froth
B.3	5	1.0	0.09	1	"

Test No.	Stirring time (mins)	Time to fill 0.5 l beaker (secs) Beaker No 1	2	3	4	5	6	DIN beaker (secs)
B.1	5	9.77	10.79	12.87	14.44	(a)	-	12.07
B.2	5	9.89	11.45	11.30	12.82	15.29(b)		11.23
B.3	5	7.16	7.94	7.95	7.99	8.69	10.64	11.25

Notes:

(a) After 2.3 litres had flowed through the filter it blocked preventing further flow.

(b) After 2.6 litres had flowed through the filter it blocked preventing further flow.

Table 18 Water soluble bag trials

Trial C - Exp 4475 (Ranger) bags and water

Test No.	Stirring time (mins)	water/ bag(l)	filter deposit weight (gms)	visual assess.	comments
C.1a	5	2.0	0.02	0.5	slight paddle wrap and froth
C.1b	5	2.0	0.04	0.5	"
C.2	5	1.0	0.50	5	disaster, tremendous paddle wrap

Test No.	Stirring time (mins)	Time to fill 0.5 l beaker (secs) Beaker No 1	2	3	4	5	DIN beaker (secs)
C.1a	5	6.77	7.65	8.33	9.53	11.25	10.68
C.1b	5	6.39	7.53	7.90	9.03	11.80	10.72
C.2	5	13.10	10.06	9.67	11.29	14.04	12.77

Note:
Test C.1 was a mixture of 3 bags and 6 litres of water, so 2 tests (C.1a and C.1b) were carried out using 3 litres for each test.

Table C.19 Field trials on Fodder Beet

Summary of statistical analysis comparing a conventional sprayer with the Dose 2000

Weed population 26 days after the application of herbicides (mean of 15 quadrat samples)

Weed	s	t
Pansy (viola arvensis)	1.66	4.62
Black Bindweed (polygonum convolvulus)	1.39	11.46
Fumitory (fumaria officinalis)	5.77	0.22

where $$s^2 = \frac{1}{n_1 + n_2 - 2}\left(\sum x_1^2 - \frac{(\sum x_1)^2}{n_1} + \sum x_2^2 - \frac{(\sum x_2)^2}{n_2}\right)$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{[(1/n_1 + 1/n_2)]}}$$

Statistics reference: Parker (1973) pp18-20

Table C.20 Field trials with fungicides

Summary of statistcal analysis comparing a conventional sprayer with the Dose 2000

(mean of 12 quadrat samples taken 4 days after the application of fungicides)

Trial	s	t
Trial A unsprayed and sprayed(leaf3)	0.21	1.72
Trial B conventional and Dose 2000		
Rynchosporium	0.03	8.94
Browm rust (Puccinia spp.)	0.01	10.47
Trial C conventional and Dose 2000		
Septoria	0.69	0.43
Brown rust (Puccinia spp.)	0.63	0.39
Dose 2000 and untreated		
Septoria	0.56	0.79
Brown rust (Puccinia spp.)	0.80	4.29

where $$s^2 = \frac{1}{n_1 + n_2 - 2}\left(\sum x_1^2 - \frac{\left(\sum x_1\right)^2}{n_1} + \sum x_2^2 - \frac{\left(\sum x_2\right)^2}{n_2}\right)$$

$$t = \frac{\tilde{x}_1 - \tilde{x}_2}{s\sqrt{[(1/n_1 + 1/n_2)]}}$$

Statistics reference: Parker (1973) pp.18-20

Table C.21 Pesticides used in the field trials at Weasenham Farms - Powders

Product	Crop	Treatment	Applic. rate	Calibration percentage
Ally (metsulfuron-methyl)	Cereals	Herbicide	30 gms in 1l at 1.0l/ha.	111
Sencorex (metribuzin)	Potatoes	Herbicide	1 kg in 1l at 1.7l/ha.	111
Ronilan (vinclozolin)	Beans	Fungicide	1kg in 1l at 1.0l/ha	95
Gesaprim (atrazine)	Maize	Herbicide	2l/ha	98
Aphox (primicarb)	S.Beet	Aphicide	280gms in 0.5 at 0.5l/ha	104

Table C.22 Pesticides used in the field trials at Weasenham Farms - Liquids

Product	Crop	Treatment	Applic. rate	Calibration percentage
Starane (fluroxypyr)	Cereals	Herbicide	0.751/ha	109
Roundup (glyphosate)	Cereals	Herbicide	2.01/ha	102
Cerone (2-chloro-ethylphos-phonic acid)	Cereals	Growth Regulator	0.751 & 0.251 Water	103
Radar (propicon-azole)	Cereals	Fungicide	1:1 water at 0.51/ha	111
Grammoxone (paraquat)	Beans	Herbicide	2.01/ha	105
Fusilade (fluazifop-P-butyl)	Sugar Beet	Herbicide	0.51/ha 1:1 water	110
MCPA	Cereals	Herbicide	21/ha	97
CMPP	Cereals	Herbicide	41/ha	103
Betanal E (phenmed-ipham)	Sugar Beet	Herbicide	2.51/ha	105
Basagran (bentazone)	Green Beans	Herbicide	0.51/ha 1:1 water	109

Figure C.1 Preparation of wash solution samples

1. Take 500ml of the wash solution, add 10mls of saturated salt solution.

2. Extract with 30ml of chloroform, using a separating funnel; run off 30mls into a rotary evaporating flask, repeat twice. Therefore 90mls in the flask.

3. Evaporate down to dryness, then place in an oven at 40°C for 1 hour.

4. Add 50mls of chloroform to prepare the final solution.

5. Reference standard: 0.1 gram into 100ml of chloroform

6. Developing solution: 90% chloroform
   10% diethylether

7. Thin Layer Chromatography plates:
   Machery Nagel SIL G-25UV$_{254}$

Reference: Lees (1991)

APPENDIX D

PREVIOUSLY PUBLISHED PAPERS

Landers, A.J.(1988) Closed system spraying - the Dose 2000. In: Aspects of Applied Biology 18, Weed control in cereals and the impact of legislation on pesticide application. pp.361-369. Warwick: Association of Applied Biologists.

Aspects of Applied Biology 18, 1988
Weed Control in Cereals and the Impact of Legislation on Pesticide Application

Closed System Spraying - the DOSE 2000

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SUMMARY

The application of micro-computer technology along with greater farmer acceptance of novel techniques, has resulted in the development of the DOSE 2000, a highly accurate dosing system for conventional sprayers.

The development of the DOSE 2000 spray application system is outlined.

The paper concludes that as more legislation is passed to control pesticide use within Europe, it will become essential to use closed system sprayers which will not only satisfy the law, but also give considerable benefits to farmers and growers.

INTRODUCTION

There is growing awareness by the general public and users of pesticides of the need to reduce environmental pollution and operator contamination.

Recent legislation in Europe seeks to control the use of pesticides and ensure their safe use on farms.

This paper reviews some of the current legislation in Europe and anticipates the need for closed system spraying.

Effective pesticide application requires accurate and safe metering by the application equipment. Recent developments in the application of electronics have resulted in the development of a dosing system that injects pesticide into a conventional crop sprayer. The principle of injecting one liquid into another is not new, examples can be found in municipal undertakings for injecting chlorine into drinking water, foam into water for aircraft fire fighters; pesticide into water on spray trains, road sweepers and irrigators, and many other industrial uses. In North America several closed system crop sprayers have been developed. Peck and Roth (1975) developed a sprayer which uses a peristaltic tube pump for liquids and a dispenser for wettable powders.

Brazelton and Akesson (1987) outlined the various principles for handling pesticides within a closed system and observed the need to bring pressure upon regulating agencies and pesticide applicators to improve working conditions. The Prairie Agricultural Machinery Institute (1986) and (1987) have evaluated a number of closed system sprayers and made recommendations to the manufacturers, particularly on modifying the system to produce faster spot spraying response.

In Europe, EHO developed a mounted closed system sprayer in Finland more than a decade ago. Lindner (1985) describes the development considerations for the Jacoby mounted direct injection sprayer.

In Australia, Humphries and West (1984) found problems with pump cavitation and pesticide viscosity and used compressed air to overcome the problems of the Terramatic.

Legislation

An increasing awareness by those who work with pesticides and the general public has led to changes in legislation governing pesticide use in Europe. In Germany, for example, Federal regulations govern correct professional conduct in plant protection. Pesticides must not be used if there is a possibility of a detrimental effect on the health of humans, animals, water sources or other damaging effects, particularly on the ecology. The Federal Government, in conjunction with the Upper House, has the power to make further regulations governing sprayers and obtain proof that these are being adhered to. Legislation is in force to ensure pesticide application equipment conforms to the standards laid down by the Department of Biology. It also carries out machine tests. The Regional Governments are also empowered to pass laws prohibiting the use of certain pesticides if they so wish.

Sweden has strict controls on certain products, for example, controls governing the use of stem shorteners on rye are in force and in particular the use of diquat is under discussion. The Swedish Government, already imposes taxes on the use of pesticides and fertilisers (37Kr per ha and 2750Kr per tonne respectively). Grants are available to farmers to cover the cost of an annual sprayer test and a number of specialised on-farm testing services have been developed.

In the United Kingdom, HM Agricultural Inspectorate investigate all cases that are reported to them regarding health and safety. The Health and Safety Executive (1988) reported that the number of cases of alleged adverse health effects reported during 1987 declined from the 1986 figure, but complaints about misuse have increased.

The Food and Environment Protection Act, Part III 1985 (FEPA) will impinge on everyone who comes into contact with pesticides, the aims are:-

a) to protect the health of humans
b) to safeguard the environment
c) to control pests safely, efficiently and humanely, and
d) to give correct label information

The Agricultural Training Board (1988) reported that 1617 courses on the 'Safe Use of Pesticides' and 496 courses on 'Field Crop Sprayers' were organised; resulting in over 18,000 operators being trained in the safe use of pesticides by 31 March 1988.

By comparison with Europe, legislation in the state of California required that a closed system be adopted for applying toxic Category One liquid pesticides as long ago as 1974. Unfortunately, no systems were available, and the enforcement of legislation was postponed until 1977. Rutz (1987) observed that it was not until 1983 that the Environment Protection Agency agreed that enforcement action would not take place provided conditions regarding protective clothing, operator training and inspection of equipment were adhered to.

It is with this background of existing legislation and any likely future legislation within Europe and California that closed systems are of interest to the manufacturer and operator of pesticide application equipment.

This paper describes the development of a closed system sprayer.

Closed system sprayers

General requirements of a closed system sprayer

a) To help the operator carry out the spraying operation safely and efficiently.

b) To allow thorough emptying and cleaning without contaminating the environment.

c) To be constructed of durable materials.

d) To inject a wide range of pesticides with varying viscosities.

e) To apply several pesticides/additives at the same time without any pre-mixing.

f) To mix the pesticide and water thoroughly.

g) To function accurately at the range of dose rates found in practice.

h) To change dose rate quickly and accurately due to changes in operating parameters.

i) To be easy to use and understand.

j) To be capable of being fitted to most existing sprayers.

k) To be commercially viable.

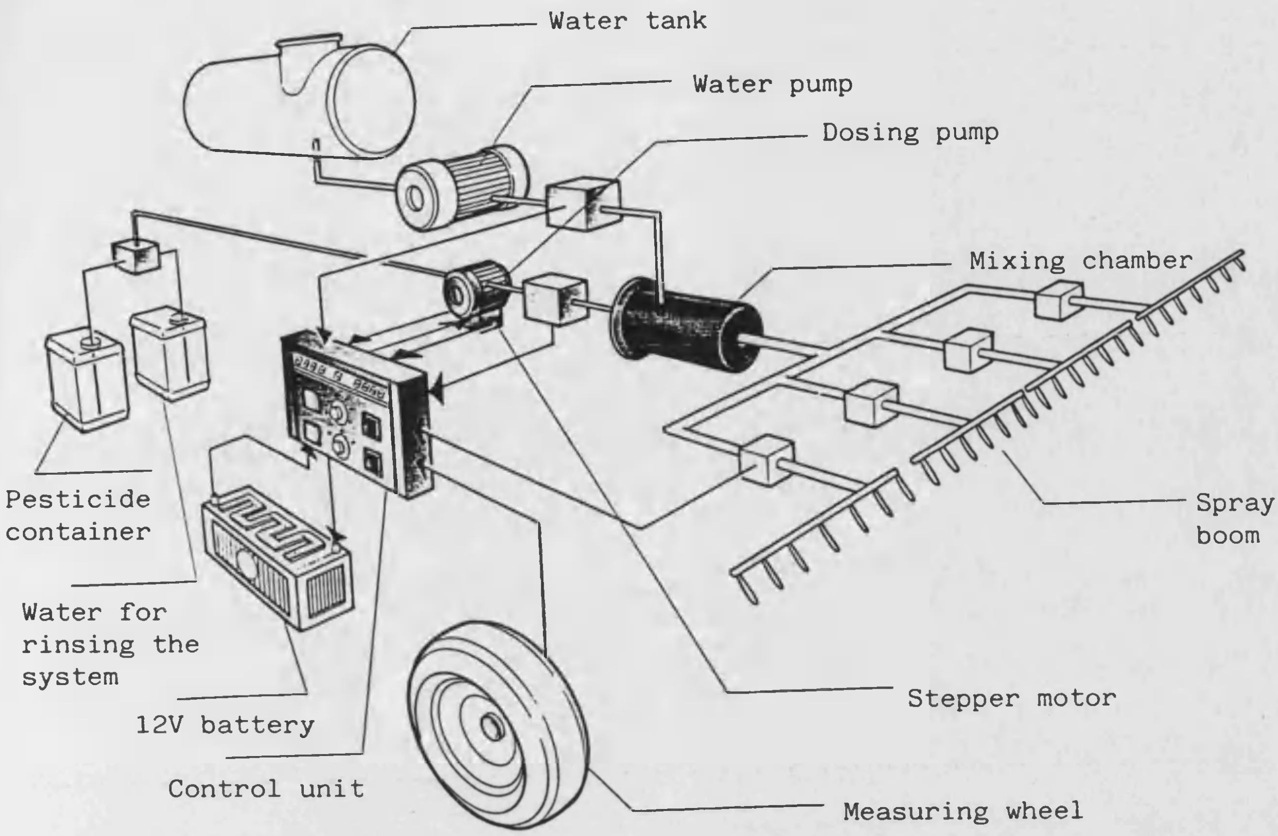

Fig.1 Components of the DOSE 2000

In trying to design a closed system technique to meet the above requirements, a large number of interacting factors need to be considered. (Wallenas, Pers. Comm.).

Description

The DOSE 2000 was developed in Sweden by Agrifutura AB International and is currently undergoing field evaluation at the Royal Agricultural College, Cirencester, Glos.

The DOSE 2000 is a kit which can be fitted to any conventional field sprayer. The kit consists of three main components:

a) containers

b) pump and monitoring unit

c) mixing chamber

Figure 1 shows components of the DOSE 2000.

The system works in the following way. The operator can select the required dose level on the control box mounted in the tractor cab. The micro-processor controlled ceramic piston pump will then pump the pesticide concentrate from the container into the mixing chamber where it mixes thoroughly with the water coming from the sprayer water pump. The solution then goes to the boom nozzles via the boom manifold valves.

a) The containers

The containers used have a capacity of 30 litres, with a wide opening to allow powders to be poured in. The size of the container is important to ensure that it matches the sprayer water tank capacity, so that this may be refilled at the same time. The weight of the full container is an important consideration; in relation to access to the container rack for lifting and the extra weight imposed upon the sprayer. The containers must empty completely, so a probe is fitted into the container, reaching down into a well formed in the base of the container. An alternative considered was to invert any containers, but problems could arise due to incorrect sealing, particularly in a farm environment.

The present situation of many small containers being required for use with large capacity tank sprayers, all needing to be rinsed and disposed of is quite a problem. Larger capacity containers allowing improved logistics, have been used in the past for seed treatment products. Perhaps the time is now right to consider returnable containers.

The 30 litres containers can be filled or rinsed out by the use of a small filling station. The electrically operated filling station comprises a suction probe, pump and filling probe. The small manufacturers' containers can be emptied into the larger container on the sprayer, and the rinsing water can also be drawn out into a separate container. This diluted waste can then be applied at a higher rate or disposed of according to the Codes of Practice, or taken away by a professional contractor.

b) The pump

The piston pump needs to be very durable to withstand the action of the pesticide concentrate and comprises a ceramic piston in a stainless steel cylinder, the seals are PTFE. The piston pump is driven via the p.t.o. input to the sprayer and is switched on only when water flow occurs through the sprayer (this is detected via a flow meter situated near the main control valve). The piston pump stroke length is adjusted according to certain parameters: forward speed (sensed by a wheel sensor on the trailed sprayer) the number of sections open and the dose level set by the operator.

The stroke length of the pump (and thus the output) is adjusted by means of an electric stepper motor, controlled by the in-cab controller. Output is directly proportional to the dose setting.

The adjustment takes into consideration the following parameters:

forward speed
number of boom sections open
pto speed into the pump
dose level set by the operator

The pump needs to be very durable to withstand the concentrate pesticide and a well-proven pump was chosen. Other simpler, cheaper, pumps such as peristaltic pumps are available, but were dismissed because of their lack of precision, reliability and longevity.

The control box on the DOSE 2000 displays the following features:

1 Dose

One of four dosing levels can be selected and the dose chosen is shown on a display, the others can be programmed in advance. During operation the dose is altered simply by switching between the various settings.

2 Calibration

Changes in parameters such as viscosity can lead to small changes in the dosing level, a simple test can be run. New settings can be inserted by press-button.

3 Remaining distance

To avoid having unused pesticide remaining in the sprayer system, the pesticide can be switched off and replaced by water as the driver nears the end of the field. The display indicates at what distance to switchover to water, thus rinsing the pipes of pesticide.

4 Tractor Speed

5 The area sprayed with each pump

6 The current flow rate of water and the total volume of water used.

In addition audio visual indicators will function when:

- pesticide container is empty
- water tank is empty
- hose leaks
- system error

Pumps 1,2,3

The operator can select any one pump or a combination of up to 3 pumps, if fitted. The spot treatment of patches of weed is a useful possibility with this system.

The controls are easy to use, and by the use of a simple magnetic card, allow a service engineer to fault-find in the sprayer system.

c) The mixing chamber

The mixing chamber is connected by a hose between the main control valve and the boom section valves. The water flow enters at the side of the chamber, and the pesticide is injected at one end of the chamber. Up to three approved products may be injected concurrently. The resulting diluent is delivered via the boom valves to the nozzles.

The mixing chamber needs to a) mix the concentrate with the water thoroughly; b) be of a large enough capacity to even out the pulsing of the piston pump (along with the rubber hoses) and, c) have a small enough capacity so as not to create a long time delay when changing dose levels. To keep time delay to a minimum the ideal position of the chamber would be at the rear of the sprayer, next to the booms. Consideration must be given to the physical constraints of mounting a closed system onto existing sprayers.

Discussion: the advantages of the Dose 2000 closed system

The closed sprayer system offers the farmer many advantages:

a) The disposal of surplus spray liquid has been a financial and environmental problem. This is minimised since the tank contains only clean water and the chemical can be returned to the store.

b) Operator and environmental contamination due to splashes when pouring, rinsing or measuring concentrates is reduced.

c) Accuracy of metering due to sophisticated electronics and precisely calibrated pumps results in financial benefits.

d) Spot treatment of weeds is readily possible, resulting in lower pesticide use on farms and its resulting benefits.

e) The logistics of spraying are improved due to less time spent at the headland mixing and calculating.

f) Nozzle throughput can be checked by using clean water.

g) Dose rate adjustments can be made whilst on the move, so, for example heavy or light infestations on headlands can be sprayed at appropriate rates.

h) The use of a distance meter allows the operator to rinse out the sprayer lines before leaving the field. The display indicates at what distance to switch off the pesticide and switch on the rinsing water.

i) A conventional spraying system is still used, which complies with existing legislation and likely future developments.

j) Water may be withdrawn from a source without fear of suck-back resulting in contamination of ponds, streams, etc.

TRIALS ON THE ROYAL AGRICULTURAL COLLEGE FARMS

The Royal Agricultural College farms extend to 740ha; emphasis is placed on commercial farming systems.

The DOSE 2000 kit was originally fitted to a Hardi 1301 LX600 sprayer fitted with a 12m boom and is now fitted to a Hardi TZ1500 sprayer with an 18m boom.

Trials with the DOSE 2000 were carried out in conjunction with the Farms Manager and staff from the Biology Department of the College. Assessments have been carried out to check the equipment mechanically and to assess the biological performance of products applied through it. The trials are still proceeding but early indications are that the DOSE 2000 can attain a level of control at least equal to that achieved by conventional sprayers.

Results will be available at the conference.

CONCLUSIONS

1 Current United Kingdom and European Community legislation has resulted in a tremendous move towards safer practices when storing, handling and applying pesticides.

2 Future legislation, brought about by increased public awareness, can only improve safety standards.

3 The advantages of closed system techniques, in avoiding environmental pollution and operator contamination, are likely to outweigh the disadvantage of the extra capital cost.

4 The ability to spot treat weed infestations will be seen by many farmers as being of great benefit in this period of falling returns.

5 There is a need for the agricultural related industries to respond to the innovative techniques available to reduce environmental pollution and operator contamination.

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APPENDIX D

PREVIOUSLY PUBLISHED PAPERS

Landers, A.J. (1989a). Closed system sprayers - the development ofthe Dose 2000. In: Agricultural Engineering: proc. 11th International Congress on Agricultural Engineering, CIGR, Dublin, September 1989. (Dodd, V.A. and Grace, P.M.eds.) pp2101-2110. Rotterdam: A.A. Balkema BV

Closed system sprayers - the design and development of the DOSE 2000

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ABSTRACT: The need for closed system spraying is discussed along with recent legislation affecting the use of pesticides in Europe and the USA. The design requirements for the DOSE 2000 closed system are outlined along with the study of closed systems at the Royal Agricultural College. The paper concludes that as legislative requirements to control pesticide use within Europe become tighter, it will be necessary to use crop sprayers which ensure the safety of the operator and avoid environmental pollution. Closed system sprayers will satisfy these demands and provide considerable benefits to farmers and growers.

RESUME: Les avantages du système clos de pulverisation sont examinés en vue de la législation récente touchant l'utilisation des pesticides en Europe et aux Etats-Unis. Les exigences techniques pour le système clos DOSE 2000 sont indiqués, aussi bien que le programme d'études des systèmes clos au Royal Agricultural College, Cirencester. A mesure que la législation sur les pesticides devient plus stricte e Europe, il sera nécessaire d'utiliser seulement ces pulverisateurs qui sauvegardent l'opérateur et éliminent la pollution de l'environnement. Les pulverisateurs en système clos satisferont à ces demandes tout en apportant des avantages aux agriculteurs et aux cultivateurs.

ZUSAMMENFASSUNG: Die Vorteile des geschlossenen Spritzsystems wird besprochen, und zwar in Zusammenhang mit neuer Gesetzgebung über die Verwendung von Pflanzenbehandlungsmitteln in Europa und in den Vereinigten Staaten. Die Bauanforderungen für das geschlossene System DOSE 2000 werden beschrieben, sowie di Forschung über geschlossene Spritzsysteme im Royal Agricultural College, Cirencester. Während die gesetzliche Forderungen strenger werden, die Verwendung von Pflanzenbehandlungsmitteln in Europa zu regulieren, wird es nötig werden, Spritzgeräte zu benutzen, die die Sicherheit des Anwenders versichern und Boden - und Umweltverschmutzung vermeiden. Geschlossene Spritzsysteme werden diese Forderungen genügen, und Bauern und Züchtern grosse Vorteile anbieten.

1 INTRODUCTION

During recent years there has been a considerable tightening of the legislation governing the application of pesticides. In the United Kingdom, the introduction of the Food and Environment Protection Act, Part II, 1985 along with the Draft Code of Practice (MAFF 1988) has resulted in the need to train operators in the safe use and handling of pesticides along with the safe operation of application equipment. Training is being carried out under the auspices of the Agricultural Training Board. Certificates of competence are issued to candidates who are successful in tests organised by the National Proficiency Tests Council.

The introduction of the Control of Substances Hazardous to Health (HSC 1989) will ensure a move towards a safer working environment. Employers will be required to make an assessment of the risks to health which arise from hazardous substance exposure, and to take precautions to protect people. The Code also states that technical or engineering methods, for example, closed systems should be considered.

Two main areas of concern with pesticide use where closed system sprayers can help, are the minimising of operator contamination and the reduction in environmental pollution.

1.1 Operator Contamination

1 Figure 1 shows areas of potential operator contamination. Splashes can be a great risk to the operator - when decanting or measuring concentrate pesticide from a manufacturer's container into a sprayer tank. The pesticide container label states the protective clothing that should be worn. (Abbott et al 1987) noted that mixing and loading the pesticide concentrate into sprayers was potentially more contaminating to the operator than the subsequent spraying of the diluted material. The extent of potential dermal exposure is quite high.

2 Nozzle blockages

Nozzle blockages require immediate attention from the operator, resulting in potential contamination. Blockages should be kept to a minimum by correct filtration. Good sprayer design should reduce this problem. Hydraulic boom folding will reduce contamination when compared with manual folding.

3 Spray drift

When spraying, drift can be a problem if the correct procedure is not followed. The correct nozzles at the correct pressure in suitable weather conditions is most important if drift is to be minimised. The use of closed tractor cabs and carbon filtration systems result in a better environment for the sprayer operator.

4 Washing out

Washing out sprayers after use is another potential hazard due to the risk of splashes generated by the use of pressure water hoses.

Good operator training and machine design will reduce operator contamination. Closed systems allow the concentrate pesticide container to be connected to the sprayer without the need for decanting or measuring. The water tank on the sprayer does not need to be rinsed as it contains clean water. (Rutz 1987) observed a decrease in mixer/loader illness with the use of closed systems in the USA.

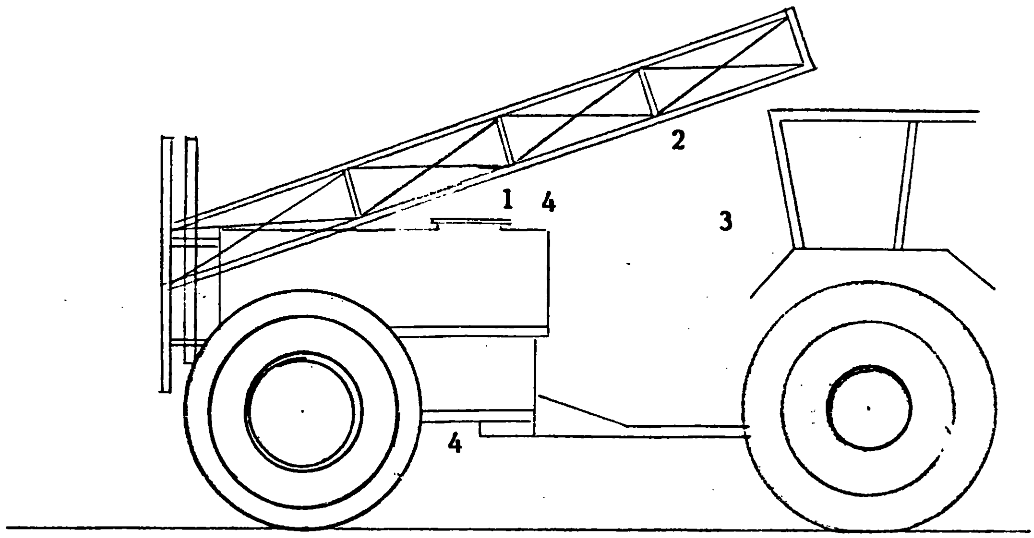

Figure 1 Areas of potential operator contamination

1 Decanting/measuring concentrate pesticide
2 Nozzle blockages/boom folding
3 Spray drift
4 Washing out

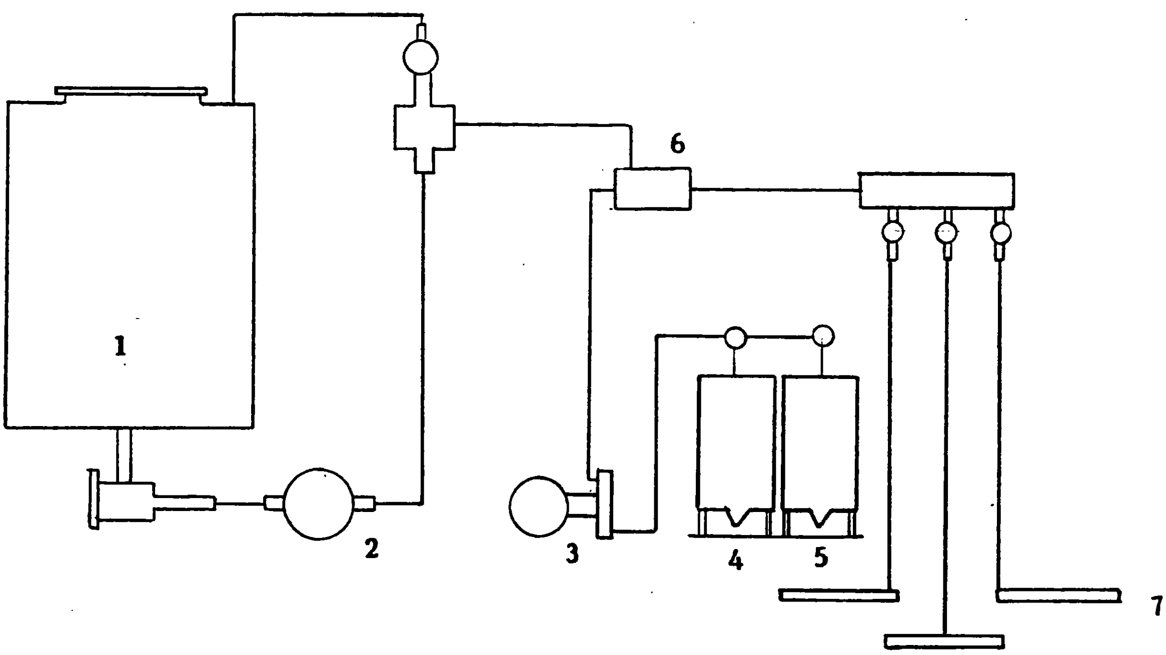

Figure 2 Schematic diagram of the DOSE 2000

1 Water tank
2 Water pump
3 Pesticide pump
4 Pesticide container
5 Water container
6 Mixing chamber
7 Booms

1.2 Environmental pollution

In recent months, widespread public concern and controversy has arisen due to nitrate residues in drinking water in the United Kingdom. Public attention is being focused on farmers' attitudes to environmental pollution.

Concentrate pesticide spillage whilst filling crop sprayers and tank residues along with tank washings after spraying can result in environmental pollution. Care and attention to detail are required and are outlined in the Code of Practice (MAFF 1988). The planned disposal of tank residues and washings on an unsprayed area of crop should result in a reduction in pollution.

Washing out tank residues thoroughly is very important; failure to do so can result in disastrous effects to crops during subsequent spraying. The degree of cleaning required will depend upon the product just applied. (Taylor et al 1988) observed that thorough cleaning, using the method proposed in the Code of Practice (MAFF 1988) took in excess of one hour, resulting in 5.2ml of pesticide remaining from a 600 litre crop sprayer. Timeliness is of the essence whilst spraying, the pesticide must be applied during the correct weather conditions and at the correct growth stage. The need to spend in excess of one hour thoroughly cleaning a sprayer is expensive in terms of labour and lost production.

The closed system spraying technique results in only clean water remaining in the sprayer water tank. This water may be released safely on to the ground without any adverse effect on the environment.

2 LEGISLATION

Legislation in many countries is affecting the application of pesticides. In Germany, for example, Federal regulations govern correct professional conduct in plant protection. The testing of application equipment is required, as it is in Sweden.

In Holland, pesticide containers must be rinsed efficiently to a standard 0.01 per cent pesticide residue.

The Ministry of Environment in Denmark aims at a 25 per cent reduction in pesticide use in agriculture before 1990 with a further reduction of 25 per cent before 1997, based upon the average use from 1981 to 1985.

In the State of California, legislation for closed systems for category one liquid pesticide was introduced in 1973. (Rutz 1987) observed that it was not until 1983 that the Environment Protection Agency agreed that enforcement action would not take place provided conditions regarding protective clothing, operator training and inspection of equipment was adhered to.

(Brazelton and Akesson 1987) outlined various principles required for handling pesticides within a closed system. They observed the need to bring pressure upon regulating agencies and pesticide operators to improve working conditions.

3 DESIGN REQUIREMENTS FOR THE DOSE 2000 CLOSED SYSTEM SPRAYER:-

1 To help the operator carry out the spraying operation safely and efficiently without incurring any risk of operator contamination.

The pesticide containers should be capable of being handled without risk of contamination and be connected via non-drip connectors. Pesticide container size should match the water tank capacity to ensure efficient sprayer operation.

2 To allow thorough emptying and cleaning without contaminating the environment.

The water tank can be drained of clean water on to the ground without fear of polluting the environment. The use of the distance remaining function allows the operator to rinse the pipelines to the boom before leaving the field.

3 To be constructed of durable materials and to withstand the effects of pesticides and solvents.

Stainless steel and ceramics can withstand such attacks. The correct choice of 'plastic' pipes and Viton or PTFE seals should be used.

4 To inject a wide range of pesticides with varying viscosities, from water soluble pesticides through dispersable granules to wettable powders.

The operator should be able to adjust the control box according to the viscosity of the pesticide, via a simple calibration procedure.

5 To apply several pesticides/additives at the same time without any pre-mixing.

This will allow up to three products approved for tank-mixing to be used. Many farmers use up to three pesticides at any one time.

6 To mix the pesticide and water thoroughly.

It is imperative that a thorough mix occurs to avoid scorching the crop or under-applying pesticide, resulting in crop loss. Vigorous mixing should be the aim.

7 To function accurately at the range of dose rates found in practice.

Arable farmers may need to apply between 0.5 litre to 10 litres per hectare of concentrated pesticide. Consideration must be given to the concentrate-pesticide viscosity in arriving at the correct dose rate via a simple calibration procedure.

8 To change dose rates quickly and accurately due to changes in operating parameters.

Examples such as changes in forward speed, engine speed and boom width. Electronic monitors should detect any changes and relay them to the control box.

9 To be easy to use and understand.

It is imperative that the operator is able to use the control box to his advantage. To obtain the maximum benefit from such a device a clear, concise manual must be provided along with a thorough training course.

10 To be capable of being fitted to most existing sprayers.

The modern crop sprayer varies considerably in its design and complexity. The injection system needs to be easily adapted to fit most machines.

11 To be commercially viable.

4 DESCRIPTION OF THE DOSE 2000

The DOSE 2000 was developed in Sweden by Agri Futura AB International. It is a kit which can be fitted to any conventional field sprayer.

The system works in the following way. The operator can select the required dose level on the control box mounted in the tractor cab. The micro-processor controlled ceramic piston pump will then pump the pesticide concentrate from the container into the mixing chamber where it mixes thoroughly with the water coming from the sprayer water pump. The solution then goes to the boom nozzles via the boom manifold valves.

Figure 2 shows a schematic diagram of the DOSE 2000 components.

4.1 The containers

The containers used have a capacity of 30 litres, with a wide opening to allow powders to be poured in. The size of the container is important to ensure that it matches the sprayer water tank capacity so that this may be refilled at the same time. The weight of the full container is an important consideration in relation to access to the container rack for lifting, and the extra weight imposed upon the sprayer. The containers must empty completely, and so a probe is fitted into the container reaching down into a well formed in the base. An alternative considered was to invert any containers, but problems could arise due to incorrect sealing particularly in a farm environment. The standardisation of container openings will allow easier connection to the suction probe.

The present situation of many small containers being required for use with large capacity tank sprayers all needing to be rinsed and disposed of is quite a problem. Larger capacity containers allowing improved logistics have been used in the past for seed treatment products. Perhaps the time is now right to consider returnable containers, as in the USA.

The 30 litre containers can be filled or rinsed out by the use of a small filling station. The electrically operated filling station comprises a suction probe, pump and filling probe. The small manufacturers' containers can be emptied into the larger container on the sprayer, and the rinsing water can also be drawn out into a separate container. This diluted waste can then be applied at a higher rate or disposed of according to the Codes of Practice, or taken away by a professional contractor.

4.2 The pump

The piston pump needs to be very durable to withstand the action of the pesticide concentrate. It comprises a ceramic piston in a stainless steel cylinder; the seals are PTFE. The piston pump is driven via the pto input to the sprayer. It is switched on only when water flow occurs through the sprayer (this is detected via a flow meter situated near the main control valve). The piston pump stroke length is adjusted according to certain parameters; forward speed (sensed by a wheel sensor or a radar speed sensor), the number of boom sections open, the dose level set by the operator, and the pto speed into the pump.

The stroke length of the pump (and thus the output) is adjusted by means of an electric stepper motor, controlled by the in-cab controller. Output is directly proportional to the dose setting.

The pump needs to be very durable to withstand the concentrate pesticide and a well-proven pump was chosen. This is used in many industrial applications, eg fluoride and chlorine dosing for water authorities. Other simpler, cheaper pumps such as peristaltic ones are available. However they are not suitable because of their lack of precision, reliability and longevity.

The control box on the DOSE 2000 displays the following features:

1 Dose

One of four dosing levels can be selected and the dose chosen is shown on a display; the others can be programmed in advance. During operation the dose is altered simply by switching between the various settings.

2 Calibration

Changes in parameters such as viscosity can lead to small changes in the dosing level; a simple test can be run. New settings can be inserted by press-button.

3 Remaining distance

To avoid having unused pesticide remaining in the sprayer system, the pesticide can be switched off and replaced by water as the driver nears the end of the field. The display indicates at what distance to switch-over to water, thus rinsing the pipes of pesticide.

4 Tractor Speed

5 The area sprayed with each pump

6 The current flow rate of water and the total volume of water used.

In addition audio visual indicators will function when:
- pesticide container is empty
- water tank is empty
- hose leaks
- system error

Pumps 1, 2, 3
The operator can select any one pump or a combination of up to 3 pumps, if fitted. The spot treatment of patches of weed is a useful possibility with this system.

The controls are easy to use, and the use of a simple magnetic card allows a service engineer to fault-find in the sprayer system.

4.3 The mixing chamber

The mixing chamber is connected by a hose between the main control valve and the boom section valves. The water flow enters at the side of the chamber, and the pesticide is injected at one end of the chamber. Up to three approved products may be injected concurrently. The resulting diluent is delivered via the boom valves to the nozzles.

The mixing chamber needs to a) mix the concentrate with the water thoroughly; b) be of a large enough capacity to even out the pulsing of the piston pump (along with the rubber hoses) and, c) have a small enough capacity so as not to create a long time delay when changing dose levels. To keep time delay to a minimum the ideal position of the chamber would be at the rear of the sprayer next to the booms. Consideration must be given to the physical constraints of mounting a closed system on to existing sprayers.

5 DISCUSSION: THE ADVANTAGES OF THE DOSE 2000 CLOSED SYSTEM

(Landers 1988) outlined the following advantages of the DOSE 2000:-

1 The disposal of surplus spray liquid has been a financial and environmental problem. This is minimised since the tank contains only clean water and the chemical can be returned to the store.

2 Operator and environmental contamination due to splashes when pouring, rinsing or measuring concentrates is reduced.

3 Accuracy of metering due to sophisticated electronics and precisely calibrated pumps results in financial benefits.

4 Spot treatment of weeds is readily possible, resulting in lower pesticide use on farms and its resulting benefits.

5 The logistics of spraying are improved due to less time spent at the headland mixing and calculating.

6 Nozzle throughput can be checked by using clean water.

7 Dose rate adjustments can be made whilst on the move so, for example, heavy or light infestation on headlands can be sprayed at appropriate rates.

8 The use of a distance meter allows the operator to rinse out the sprayer lines before leaving the field. The display indicates at what distance to switch off the pesticide and switch on the rinsing water.

9 A conventional spraying system is still used, which complies with existing legislation and likely future developments.

10 Water may be withdrawn from a source without fear of suck-back resulting in contamination of ponds, streams, etc.

6 EVALUATION TRIALS AT THE ROYAL AGRICULTURAL COLLEGE FARMS

The Royal Agricultural College farms extend to 740ha, where emphasis is placed on commercial farming systems. Trials were carried out in conjunction with the Farms Manager and staff from the Engineering and Biology Departments of the College. The DOSE 2000 has been evaluated on different crops using pesticides at various application rates during 1988. The biological performance has been assessed along with the following mechanical evaluation:-

6.1 Ease of installation

The attachment of the dosing system to the conventional sprayers was studied. The dosing system could be installed within a few hours; the amount of plumbing required is quite small but the power take-off and pulley needs an extra guard in some cases.

6.2 Ease of operation of the control box

There is a need for a comprehensive operator manual. The ease of use was evaluated in respect of the controls and the display. The dose rate was easy to set and adjust; the water flow rates, forward speed and area were easily monitored via digital display.

6.3 Field operation

The filling of the pesticide container required the correct protective clothing and skills as the filling of a conventional sprayer. (This operation would be simpler if larger pesticide containers were commercially available which could be fitted directly on to the sprayer).

The couplings connecting the pesticide containers to the dosing unit pipes operated without problems. The accuracy of the dosing pump has been observed. The pump is extremely accurate with water and aqueous solutions, but further research is needed into the viscosities of various pesticides. The dose level can easily be adjusted by means of a press-button.

Calibration was straightforward using the calibration vessel and the area meter. Numerous calibrations trials with water have been carried out to ensure accuracy before applying any pesticides.

Spot spraying response times were recorded using paraquat on grassland. The response time to a change in dose rate or the introduction of a pesticide was clearly observed. Modification of the sprayer could result in a response time of five seconds on the 18 metre sprayer applying 200 litres/ha.

6.4 Mechanical reliability

The DOSE 2000 was used with numerous pesticides throughout the course of the spraying season. The only problem has been the need to replace the dosing pump seals of Viton with seals made from PTFE.

6.5 Further studies

Further studies are to be carried out on viscosities, and the effect on timelines of the spraying operation due to faster turnround on the headlands (due to not having to mix or measure concentrated pesticides or rinse out the water tank).

7 CONCLUSIONS

1 Current United Kingdom and European Community legislation has resulted in a significant move towards safer practices when storing, handling and applying pesticides.

Future legislation, brought about by Governments and public awareness, can only improve safety standards. As more emphasis is placed upon safer use of pesticides such as the Control of Substances Hazardous to Health, so there will be a greater need for closed system sprayers to avoid operator contamination and environmental pollution.

2 The advantages of closed system techniques in avoiding operator contamination and environmental pollution, are likely to outweigh the disadvantage of the extra capital cost. The advantages of not having to measure or decant pesticide at the headland, coupled with not needing to wash or rinse the main tank, will result in a saving of time, leading to improved work rates.

3 The advantages of being able to spot treat as and when required, along with the ability to change dose rates as levels of infestation alter, will be of considerable benefit to farmers during this period of lower profit margins.

4 There is a need for the agriculture-related industries to respond to innovative techniques to reduce environmental pollution and operator contamination. There is also a need for standardisation of container openings to allow universal couplings to be connected along with a larger choice of pack size to match sprayer tank capacity.

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APPENDIX D

PREVIOUSLY PUBLISHED PAPERS

Landers, A.J. (1989b). Injection closed system sprayers.*Pesticide Outlook*. 1 (1),27-30

INJECTION CLOSED SYSTEM SPRAYERS

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The increasing awareness of environmental pollution and operator safety when handling agricultural pesticides has resulted in the development of direct injection closed system sprayers. Also with the profit margins of farmers decreasing, there is a great need for accuracy, timeliness and crop safety if optimum use of pesticides is to be achieved. Pesticide injection and sprayer monitoring techniques are advancing rapidly with the application of electronics. In the light of new developments, this article examines existing and developing designs of closed system direct injection sprayers, along with their relative merits.

In 1988 pesticide use in British Agriculture amounted to 23,504 tonnes of active ingredients worth £ 409 million, most of it being applied to cereals (BAA, 1989). The high cost of pesticides, in a period of financial uncertainty, has resulted in many farmers considering the accuracy of their application methods very carefully.

The accuracy of spraying is being enhanced by the training of operators to meet the requirements of the Food and Environment Protection Act, 1985. Also the introduction of the Control of Substances Hazardous to Health (HSC, 1988) in October 1989 will encourage farmers to make an assessment of the risks to health when using pesticides, and to take precautions to protect the operator. The use of technical or engineering methods such as closed systems should therefore be considered.

An increasing public awareness of environmental issues, particularly pollution, has resulted in greater care being exercised with pesticide residues. The Water Authorities and the Ministry of Agriculture, Fisheries and Food are co-operating with farmers to reduce pollution levels from agriculture. As pollution monitoring equipment becomes more sensitive, the admissible concentration levels are being questioned by certain sectors of society.

The Basic Concept

A conventional crop sprayer is fitted with an injection system comprising one to three pumps which will dispense pesticide at a known rate into the water stream in the sprayer pipeline. The main tank of the sprayer holds clean water only. The pesticide is mixed with the water, either in a manifold or at the main water pump, and the solution of pesticide and water flows to the booms. A controller adjusts the pesticide pump output according to changes in operating parameters, e.g. boom sections switched on/off, changes in forward speed, etc. Monitors inform the controller of any change. In an ideal world, the pesticide would be transferred from the original container directly into the water via the injection pump.

Historic Overview

Development of direct injection closed system sprayers has continued for many years in Europe. Amsden (1970) outlined various methods of metering pesticide into water on agricultural crop sprayers and railway trains. In 1976 a Betanal injection system for row spraying was developed in Holland using propane gas to pressurise the system. A later version in 1980 utilised an air compressor. In the mid -1970s the Finnish company, EHO, used a small piston pump with variable stroke length for pesticide transfer. In 1982 the GDE system was developed in Germany by Conduria, a 3 piston displacement pump, with one double stroke per piston and revolution was used to pump pesticide into the water line.

The Microcide Injection System used peristaltic pumps for different pesticides. This development occurred in the UK in the early 1980s and part of the diluent was recirculated from the boom end nozzles, thus allowing for an improvement in the speed of response. Landers (1988) outlined the various principles for handling pesticides within a closed system being developed in North America and Australia during the 1970s and 1980s.

Commercially Available Direct Injection Systems

There are two systems currently available in the UK, the AgriFutura Dose 2000 and the Walsh CCI-2000.

The AgriFutura Dose 2000

This system has been developed in Sweden by AgriFutura ab over the last five years and evaluation trials have been carried out at the Royal Agricultural College, Cirencester for the past 18 months (Landers, 1988). The system is a kit which can be fitted to any conventional field sprayer (Fig. 1).

The 30 litre containers are filled with pesticide in the chemical store using a filling station. The filling station allows the operator to remove pesticide from the manufacturer's original, small containers into the larger container. It is important that container size matches the ratio of pesticide to water application to avoid running out of pesticide before the water tank is empty. The containers are fitted to the side of the sprayer.

The pesticide is withdrawn from the container by means of a probe connected via a pipe to a dosing pump. This comprises a ceramic piston operating in a stainless steel cylinder; the piston stroke length is altered by a stepper motor and gearbox. Power input is via the tractor power

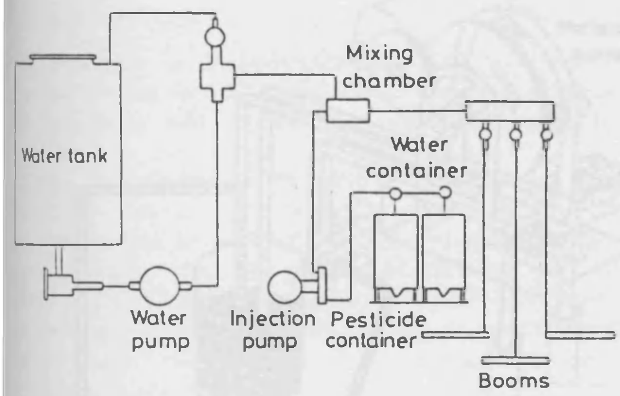

Figure 1. The AgriFutura dose 2000.

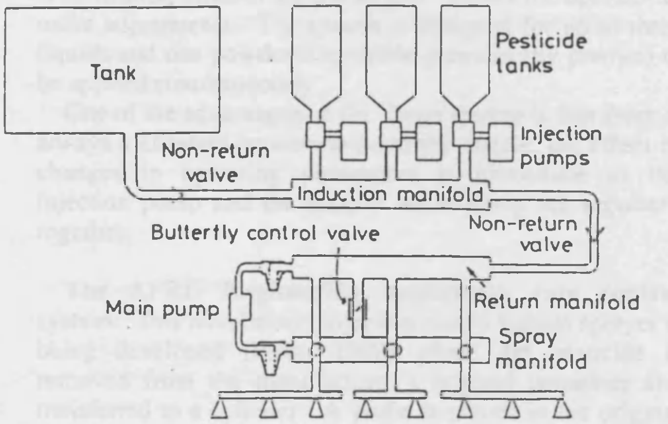

Figure 2. The Walsh CCI-2000.

take off. Any changes in operating parameters result in the stepper motor altering the stroke length, thereby increasing or decreasing the amount of pesticide injected. Pesticide is delivered by pipes to a mixing chamber, situated between the water pressure regulating valve and the boom selection valves, where it joins with clean water from the sprayer tank. The diluent then passes out to the boom. The in-cab controller displays a number of features:-

a) Dose Level - up to four dose levels can be selected and displayed on the screen. Dose level adjustment is made by simply pressing an increase/decrease button.

b) Pumps 1, 2, 3 - the operator can use pumps one to three to inject compatible products as and when required, e.g. spot treatment.

c) Calibration - a calibration factor can be entered to take into account different viscosities of products.

d) Distance Remaining - this allows the operator to see at what distance he has to change from pesticide to rinsing water to decontaminate the sprayer.

e) Alarms - a number of audio-visual alarms are fitted to alert the driver when pesticide or water is running low, a hose leaks, speed is too fast/slow or other system errors.

Other features include tractor speed, area sprayed and water flow.

The Walsh CCI-2000

This was developed in the USA in the mid-1980s and has been imported and modified by Handbury Machinery Services for the past two years (Handbury, 1989). The system (Fig. 2) comprises individual cone bottom pesticide tanks as up to three pesticides may be applied. The tanks are connected to peristaltic tube pumps which meter the pesticide into the induction manifold where it joins with clean water from the sprayer water tank. The pumps are driven by 12 volt variable speed electric motors. By varying the motor speed and tube size, the pumps can inject pesticide within a wide range of application rates.

The diluent passes through the stainless steel return manifold, through the sprayer pump and into the spray manifold. Boom control values allow the diluent to pass to the booms, if a boom selection is switched off the diluent goes back into the return manifold. The manifold system has been developed to reduce the delay found on the original system. The use of a butterfly control valve controls the amount of diluent being sprayed in relation to forward speed (DPA). Non-return valves ensure that no diluent goes into the water tank.

The in-cab console controls pump output, compensates for changes in speed and volume, and can control up to three pumps individually or simultaneously. The area sprayed and the amount applied are also measured. The CCI controller has an increase/decrease button which allows the operator to override the pump setting in 5% intervals. This is useful for adjusting dose rate for heavy/light infestations, or the spot treatment of weeds. Boom selection switches allow each boom section to be switched on/off independently: the console automatically controls pump output.

The console display informs the operator of travel speed, application rate, width of boom, number of nozzles, distance travelled and the percentage increase/decrease in dose rate. Error signals inform the driver of any problems regarding forward speed or system malfunction. One of the features of the Walsh CCI-2000 is the printer module which provides the operator with a record of application rate of pesticide applied, area covered, time, date and location data. Also of use is the calibration information which provides the operator with a reference of input data, e.g. application rates, totals and pump calibration numbers.

Systems Currently Under Development

Four systems are being developed at present, one by the Dutch company Vicon, one by the Agricultural and Food Research Council (AFRC) Engineering, Silsoe and two others which are subject to commercial secrecy.

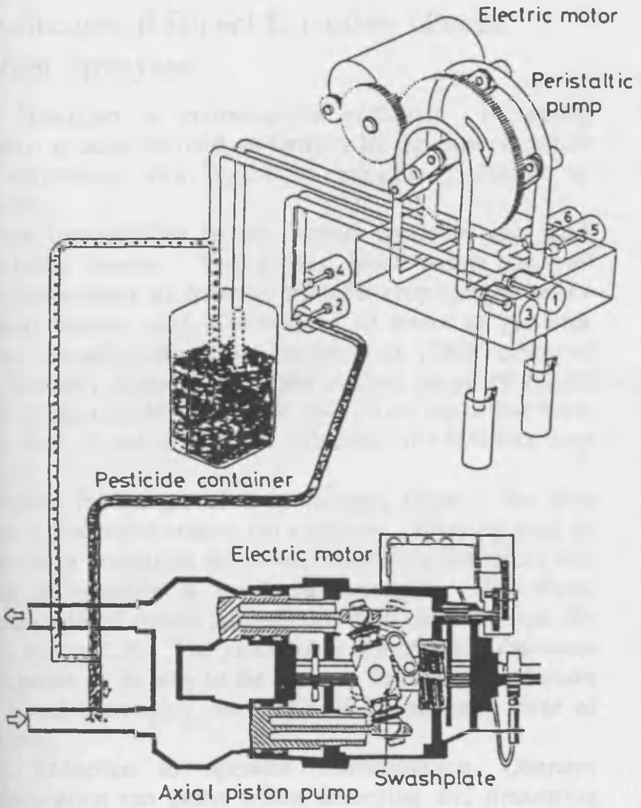

Figure 3. The Vicon Injection System.

The Vicon Injection System: The Vicon Agricultural Machinery Company is developing a direct injection closed system sprayer in Holland and England (Beijaard, 1989). Figure 3 shows the layout of the system.

The injection system comprises a dual tube peristaltic pump. This pump has both a large bore and small bore tube, which allows the operator to select a wide range of application rates. The dual tube peristaltic pump is driven by a variable speed electric motor. The pesticide is removed from the container by means of a probe via the pump to the inlet side of the main sprayer water pump. The quantity of pesticide being injected can be altered by varying the speed of the electric motor.

The pesticide joins the flow of water and is thoroughly mixed as it passes through the water pump and out to the sprayer boom. The water pump is an axial piston pump (swashplate pump) and so the output can be altered according to requirements, e.g. change in speed, boom selection being shut off, etc. The change in output is affected by moving the swashplate via an electric motor, thereby adjusting the stroke of the pistons.

The dual tube peristaltic pump and main water pump can be regulated together. This allows for a change in pump output whilst maintaining a constant concentration of pesticide in the water. A series of electrically controlled valves allows the operator immediately to stop injecting pesticide and also return the pesticide back to the container.

A controller, fitted in the tractor cab, allows the operator to make adjustments. The system is designed for up to three liquids and one powder/dispersible granules (by premix) to be applied simultaneously.

One of the advantages of the Vicon system is that there is always a constant concentration at the nozzle, the effect of changes in operating parameters is immediate as the injection pump and the sprayer water pump are regulated together.

The AFRC Engineering application rate control system: This novel direct injection closed system sprayer is being developed (Frost, 1989) where the pesticide is removed from the manufacturer's original container and transferred to a cylinder. A probe is placed in the original container and suction is created by a piston moving within the cylinder and thereby withdrawing the pesticide. The piston is moved within the cylinder by means of water being withdrawn from one side of the piston. A venturi, situated in the sprayer return line between the water pump and the water tank, creates the suction. This action is similar to that of a hypodermic syringe (Fig. 4).

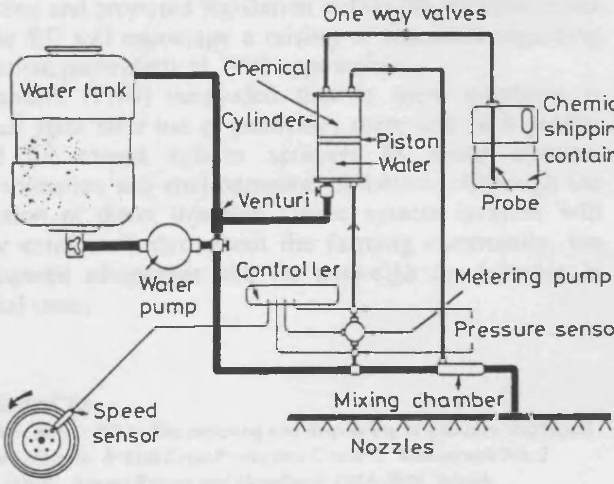

Figure 4. The AFRC Engineering Injection System.

The piston direction can be reversed within the cylinder, thus pushing out the pesticide into a mixing chamber situated in the sprayer water line between the water pump and the boom. The piston is pushed by means of a metering pump which withdraws water from the main water line. The pressure sensors are used to monitor the difference in pressure at the metering pump. The controller calculates the flow rate, due to pressure differences either side of the pump, pump speed and forward speed. The flow rate of water into the cylinder is equal to the flow rate of pesticide from it.

There are a number of advantages in using water through the metering pump, firstly it removes the problems associated with pesticide viscosities and flow rates and secondly, water is less harmful than pesticides to the metering pumps and their seals.

Advantages of Direct Injection Closed System Sprayers

1. Reduction in environmental pollution. Increasing attention is being focused on farmers by the general public and legislation with regard to possible pollution by pesticides.

Crop susceptibility to the wrong pesticide can have devastating results. The farmer must ensure that all pesticide residues are removed from the crop sprayer before spraying another crop. To remove all traces of pesticide residue can take some time. Taylor, *et al.* (1988) observed that thorough cleaning, using the method proposed by the Code of Practice (MAFF, 1988), took in excess of one hour. As a result, 5.2ml of pesticide remained in a 600 litre crop sprayer.

Besides the danger of crop damage, there is the time taken in thoroughly rinsing out a sprayer. Spraying must be done whilst conditions are correct, therefore any delay will result in reduction in the 'spray window'. The direct injection closed system sprayer uses only clean water in the main sprayer tank. The pesticide is injected into the water as it passes on its way to the booms. Providing the booms are rinsed thoroughly, there should be no carry over of pesticide.

2. Reduction in operator contamination. Operator contamination can occur whilst decanting and measuring pesticide in a conventional system. In an ideal situation, the pesticide transfer could be totally closed. The pesticide container could be fitted to the side of the sprayer and a probe connected directly to the container, puncturing the seal. The operator would therefore be protected from any splashes, the environment protected from any spillage and no financial loss would be incurred. The use of a low level container rack would reduce the physical lifting required by certain crop sprayers.

3. Accuracy of metering. The direct injection systems use either piston pumps or peristaltic tube pumps in conjunction with electronic controllers. The accuracy obtained will depend upon the quality and maintenance of the pump.

4. Spot treatment. Spot treatment of weeds or diseases can easily be carried out. The operator can switch on extra pumps as and when required. This will result in lower pesticide use on farms.

5. Adjustment of dose rate. The dose rate can be adjusted whilst on the move, thus accommodating different levels of infestation, different soil types and headland spraying.

6. Logistics of spraying. The logistics of spraying are improved due to less time being spent calculating quantities, pouring and measuring pesticides at the headland. The operator need only connect the pesticide container and refill the water tank with clean water. The in-cab monitor is used to set the dose rate.

7. Frothing. The injection of pesticide into the water eliminates the frothing which can occur in the main water tank of conventional systems, particularly with severe agitation.

8. Flushing systems. The use of distance-remaining features allows most systems to switch from pesticide to clean water, thus flushing out the system and decontaminating the spray lines.

9. Fitting. The direct injection closed systems can be fitted to most conventional sprayers.

Conclusions

Firstly, direct injection closed systems offer considerable safety and environmental advantages by reducing operator contamination and removing the need to dispose of tank residues. Secondly container neck dimensional thread size standardisation to 63mm and 45mm by the members of GIFAP (International Group of National Associations of Manufacturers of Agrochemical Products) will allow further development of standard connectors and probes. This will enable the direct injection sprayers to become fully closed systems. Increasing public awareness about the use of pesticides and the environment will result in pressure upon legislators to act accordingly. The advantage of not having sprayer tank residues will interest many legislators. Existing and proposed legislation within the member states of the EC will encourage a raising of standards regarding pollution, particularly as 1992 approaches.

Landers (1989) concluded that as more emphasis is placed upon safer use of pesticides there will be a greater need for closed system sprayers to avoid operator contamination and environmental pollution. Although the adoption of direct injection closed system sprayers will incur extra costs throughout the farming community, the undisputed advantages will far outweigh the increase in capital costs.

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APPENDIX D

PREVIOUSLY PUBLISHED PAPERS

Landers, A.J.(1989c). *The effect of legislation on the application of pesticides in the State of California.* Cirencester:Royal Agricultural College.

THE EFFECT OF LEGISLATION

ON THE APPLICATION OF PESTICIDES

IN THE STATE OF CALIFORNIA

A report by

ANDREW LANDERS
Senior Lecturer in Agricultural Mechanization

SUMMARY

California has become the model for many Federal and State Laws governing pesticide use in the USA. In 1973 California required the use of closed systems for Category One toxic pesticides. A one month study tour, based at the University of California, Davis, was carried out by the author into current and future legislation affecting pesticide use. Closed systems are used by some applicators for all pesticides. Good sprayer waste management is being encouraged by training and legislation. Returnable containers are gaining in popularity as they reduce environmental problems. The implementation of closed systems in the UK will reduce operator contamination and environmental pollution, guidelines to their design must be laid down to advise the sprayer manufacturer and operator.

1st October 1989

CONTENTS

1 INTRODUCTION

Concern for the safe handling of pesticides has increased considerably in recent years and the introduction of legislation has helped protect the operator and reduce environmental contamination. In California, the increased public awareness of pesticide use and residues in food and groundwater has heightened the debate, resulting in very strict legislation governing all aspects of pesticide use. California has become the model for many Federal and State laws in the United States of America.

The transfer, mixing and application of pesticides has for a long time been an area for great concern, and in 1973 California law first required the use of closed mixing systems for Category One toxic pesticides. However enforcement was moved to January 1978 because of the lack of suitable systems.

A closed mixing system comprises of a method of extracting pesticide from the original pesticide container and transferring it to the water/mixing tank on the crop sprayer, thus, along with protective clothing, maximising operator safety.

California is the third largest state in the United States, an area of about 158,693 square miles, three quarters of which being rolling hills and high mountainous country. The combination of fertile soils, a Mediterranean climate and irrigation provide ideal growing conditions. The area cultivated represents only 3% of the nation's total farmland, and this produces nearly 10% of the country's agricultural cash receipts.

Of the 250 different agricultural commodities grown in the US California produces more than 220 and ranks first in the production of 48 of them. California also produces 52% of the fresh market vegetables, 55% of the processing vegetables and 50% of the fruits and nuts. Appendix 1 (Demment et al 1989) shows the diversity of crops grown and their value - approximately $15,000 million.

Recorded pesticide use within the State of California amounted to 93,888,065 lbs of active ingredient (CDFA 1989).

The introduction of the Control of Substances Hazardous to Health, (HSC 1988) in October 1989 in the United Kingdom, will encourage farmers and growers to make an assessment of the risks to health when using pesticides, and to take precautions to protect the operator. One area to consider under technical or engineering methods is the use of closed systems.

This report is based upon a one month research project carried out in California, based at the University of California-Davis. The research was conducted by:

a) interviews with legislators, State officials, academics, researchers, farmers/growers, custom applicators and manufacturers within the State and

b) a literature review in the libraries of Agricultural Engineering and Environmental Toxicology.

This report describes the existing and proposed legislation affecting :

1) design and use of closed system sprayers
2) reduction in operator contamination
3) reduction in groundwater pollution
4) container disposal
5) operator training and certification

2 PESTICIDE USE IN CALIFORNIA

2.1 An Overview

93,888,065 lbs of pesticides were recorded for agricultural use in 1987 (CDFA 1989). The majority (60%) of pesticides were applied by aircraft; there are approximately 180 aerial applicators, using around 700 aircraft.

30% of the pesticides applied were Category One or Two, the remaining, less hazardous, products are in Category Three and Four. Category One products - see Appendix 2 - are designated as products having an oral LD50 of less than 50 mg/kg body weight.

The California Department of Food and Agriculture state that all Category One and some Category Two pesticides should be used via closed transfer and mixing systems.

2.1.1 Legislation

Many federal and State laws and regulations affect the manufacture, storage, sale, transportation and use of pesticides.

The Environmental Protection Agency (EPA) controls the use of pesticides at a national or federal level.

The California Department of Food and Agriculture (CDFA) write the regulations regarding pesticide use in the State of California.

The State has a number of other departments interested in pesticide use and disposal, viz:
Department of Health Services
Department of Fish and Game
Occupational Safety and Health Administration
Waste Management Board
Department of Water Resources
Water Resources Control Board
Department of Consumer Affairs

Appendix 3 (Stimmann 1988) shows the responsibilities of the various government agencies in California's Pesticide Regulatory Program. The Appendix shows who controls each aspect of legislation and what work each department carries out.

Fig.1 Closed Systems: the closed transfer of pesticide from the shipping container to a closed mixing tank or crop sprayer.

Individual Counties within the State can also create their own recommendations regarding pesticide use via the permit system.

2.1.2 Pesticide Registration

Each pesticide is registered with the Environmental Protection Agency (EPA) as well as the California Department of Food and Agriculture (CFDA). Each product is evaluated as to whether the material can be classified as a general-use pesticide or as a restricted-use pesticide (see Appendix 4 for list of restricted materials).

2.2 Design and Use of Closed System Sprayers

2.2.1 Definition: the closed transfer of pesticide from the shipping container to a closed mixing tank. Brazelton and Akesson (1986) describes a basic closed mixing and handling system, see Appendix 10. All Category 1 and some Category 2 pesticides must be used in a closed system.

2.2.2 The development of closed system Sprayers

The CDFA introduced regulations stating that closed systems be adopted for Category 1 pesticides in 1974. Specific criteria was developed later and due to a dearth of equipment, the regulations were not implemented until 1977.

Appendix 11 states the criteria for Closed Liquid Pesticide systems, as drawn up by the CDFA (Pesticide Enforcement Branch). People interested in designing and manufacturing closed systems are able to refer to the criteria for guidelines.

2.2.3 Closed system designs

There are 17 companies supplying closed systems which have been observed by the CDFA and which appear to meet the Directors closed system criteria. Appendix 12 lists these manufacturers and codes outline their use with containers, closures and any limitations the system may have. The systems vary from simple probes, eg Cherlor Manufacturing Co Inc and Protect-o-Manufacturing to devices which drain, rinse and damage the container eg the Goodwin can opener, and "Captain Crunch".

During my visit to numerous farms and custom applicators the following four devices were by far the most popular:

2.2.3.1 <u>Cherlor Manufacturing Co Inc</u>

This company manufacturer a probe system and a separate rinsing system, diagrams are to be found in Appendix 13.

The Cherlor Chemprobe Maxi-load comprises a telescopic probe which can be screwed on to the can opening; different caps are available for different can openings. The pesticide is withdrawn by means of a vacuum, created by a venturi, into the sprayer or mixing tank.

The Cherlor Chemeasure is a similar probe design, but is fitted to a transparent graduated measuring cylinder. A simple hand movement causes the pesticide to move under vacuum from the original container, via the cylinder to the sprayer tank or mixing tank. All parts of the probe that extend into the chemical container retract into the Chemeasure body.

Empty containers are inverted on to a rotating nozzle in a polythene basin on the Chemrinse. Clean water is sprayed into the container, the container remaining inside the basin until it is rinsed, thus allowing the operator to carry on with another task. Rinsewater and residues drain by gravity through a transparent tube to the sprayer. The operator can thus tell when the container is clean.

The major advantage of the Cherlor probe and separate rinsing system is that there is no possibility of rinsing water entering a part-used container.

2.2.3.2 <u>The Protect-o-Manufacturing Co</u>

A probe is inserted into the container opening, in some cases destroying the opening, and so preventing any re-seal. The pesticide is removed under vacuum and enters the sprayer or mixer tank. The probe can be pushed into the container to a pre-set depth, so only removing a desired amount.

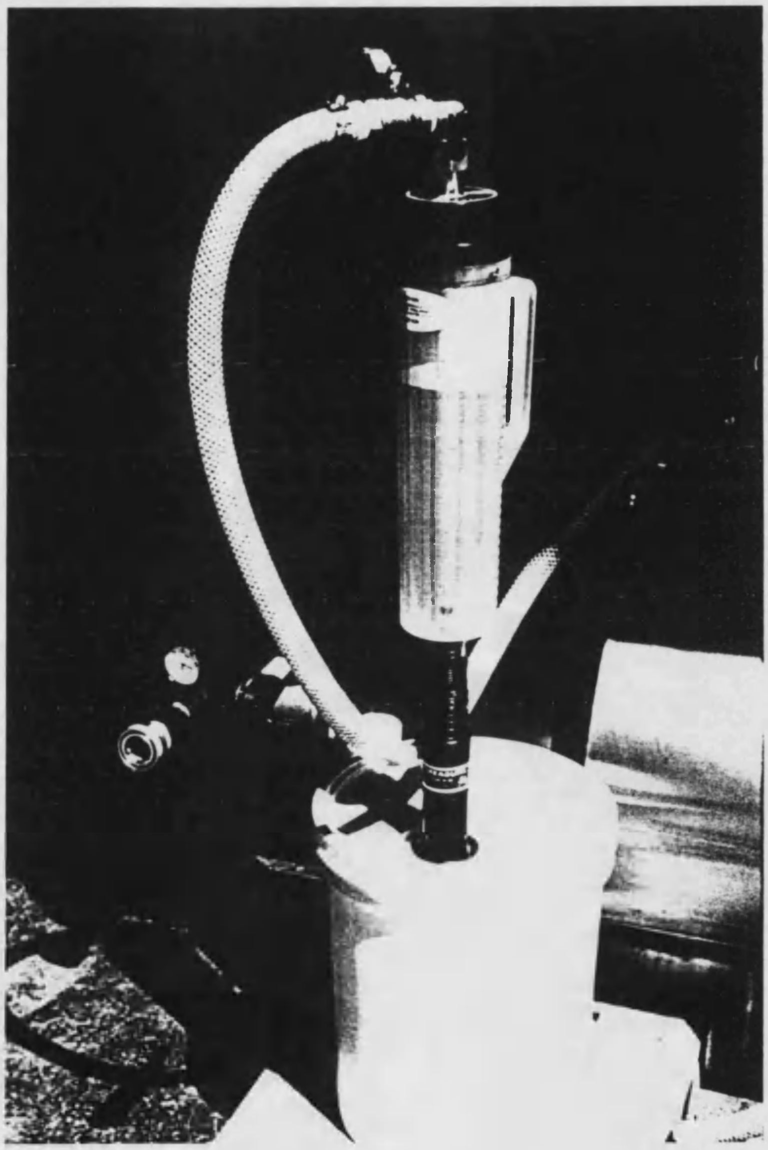

Fig.2 The Cherlor Chemeasure attached to a container.

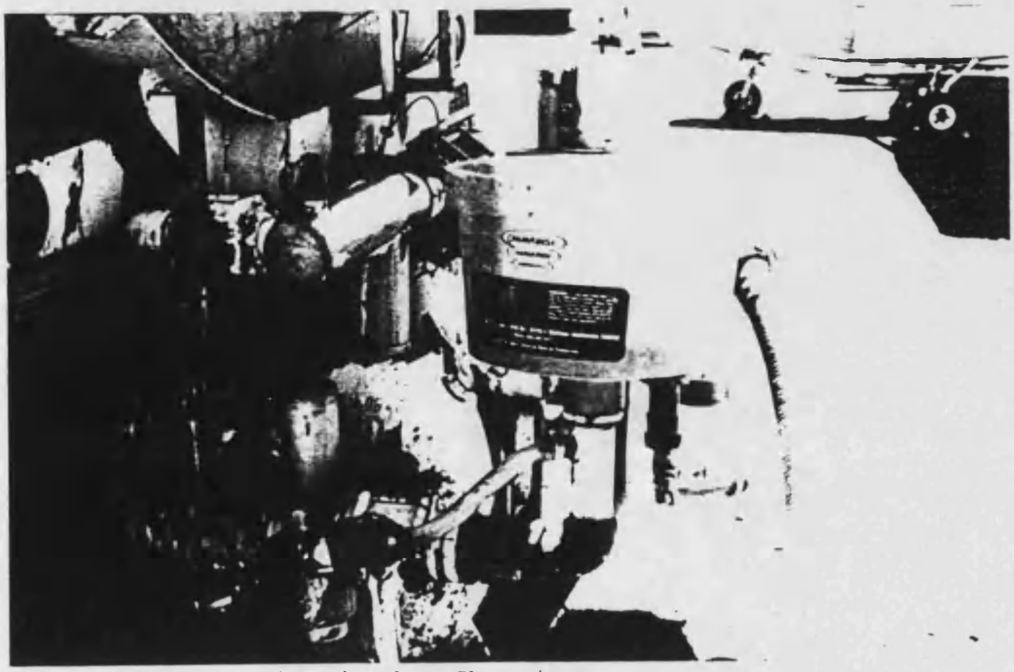

Fig.3 The Cherlor Chemrinse

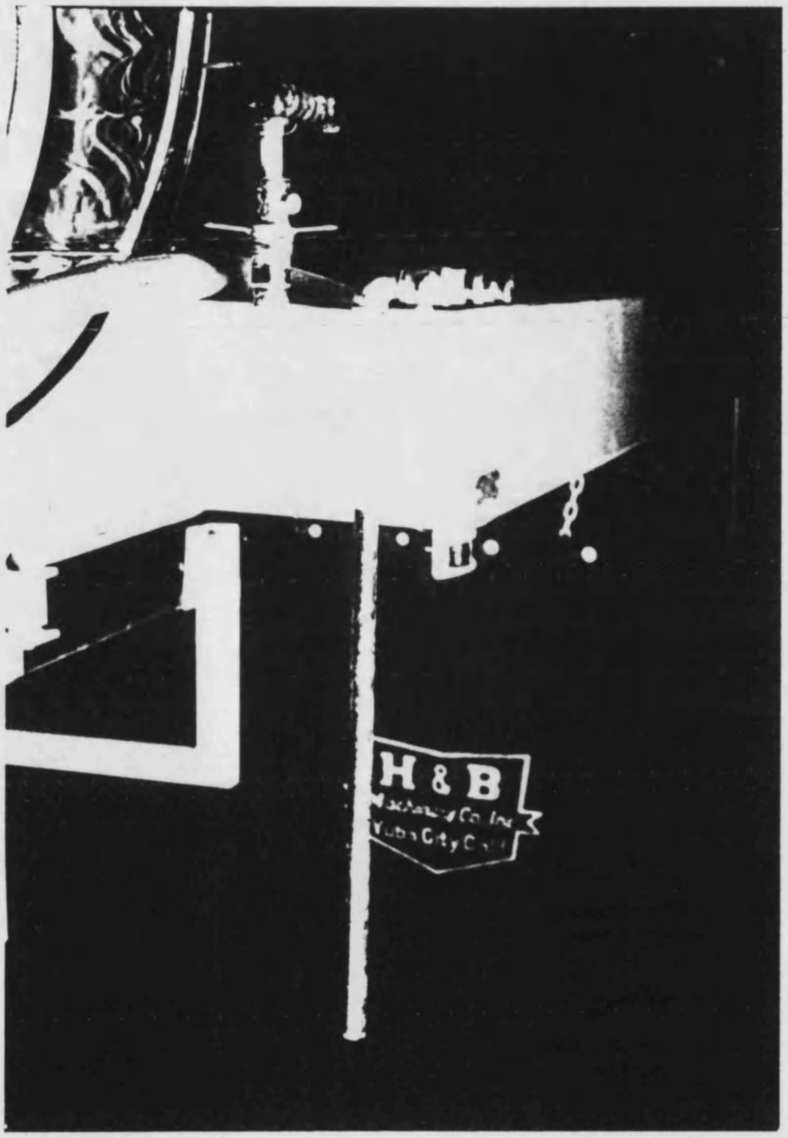

Fig.4 The Protect-o-Manufacturing Co probe for small containers and a larger probe for 45 gallon containers on a mixing truck.

When the probe is extracted from the container a small "O" ring wipes the pesticide from the probe as it is withdrawn. In the rinsing mode water is introduced through a second connector and sprays around the inside of the container via slots in the probe. The rinsate is removed by vacuum in the same manner as the pesticide. Appendix 14 shows the probe.

2.2.3.3 The Goodwin Can Opener

The Goodwin Can Opener (Appendix 15) accepts a wide range of containers, between 1 and 5 gallons, metal or plastic. The container is placed inside a stainless steel box and the lid is closed. A handle is pulled which punctures the container, pesticide runs out into the stainless steel box. A sight-gauge, mounted on the side of the box tells the operator when all the contents have drained out of the container. The knife, which punctured the container, has a water rinsing pipe connected to it. This allows rinsing water to be introduced through the knife into the container. The rinsate enters the pipework to the sprayer.

The major advantage of this closed system is that there are no problems with the different size of container openings. The major disadvantage is that the container is destroyed by the slits, therefore the whole of the container contents must be used, which must lead to problems regarding part quantities of pesticides.

2.2.3.4 Captain Crunch

This system can handle up to 5 gallon plastic or metal containers. The container is placed into the unit (Appendix 16); a hydraulic cylinder pushes the container on to stainless steel knives which cut the bottom of the container allowing the contents to fall into the stainless steel holding tank. A lever is then pulled to introduce rinsing water into the container.

The hydraulic cylinder then crushes the container to one-fifth the original size.

The major advantage of 'Captain Crunch' is that the container is crushed and rinsed, so takes up less space for disposal. The disadvantage is part-use of container contents, as the container is totally destroyed.

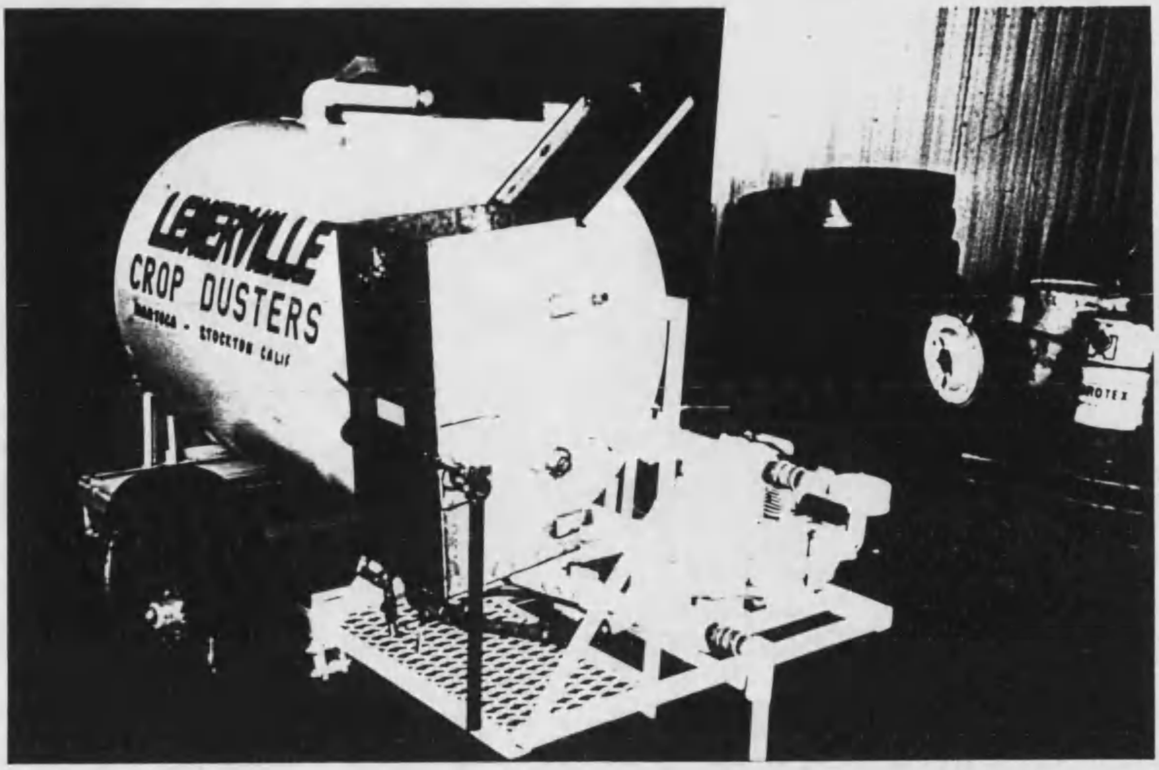

Fig.5 The Goodwin Can Opener

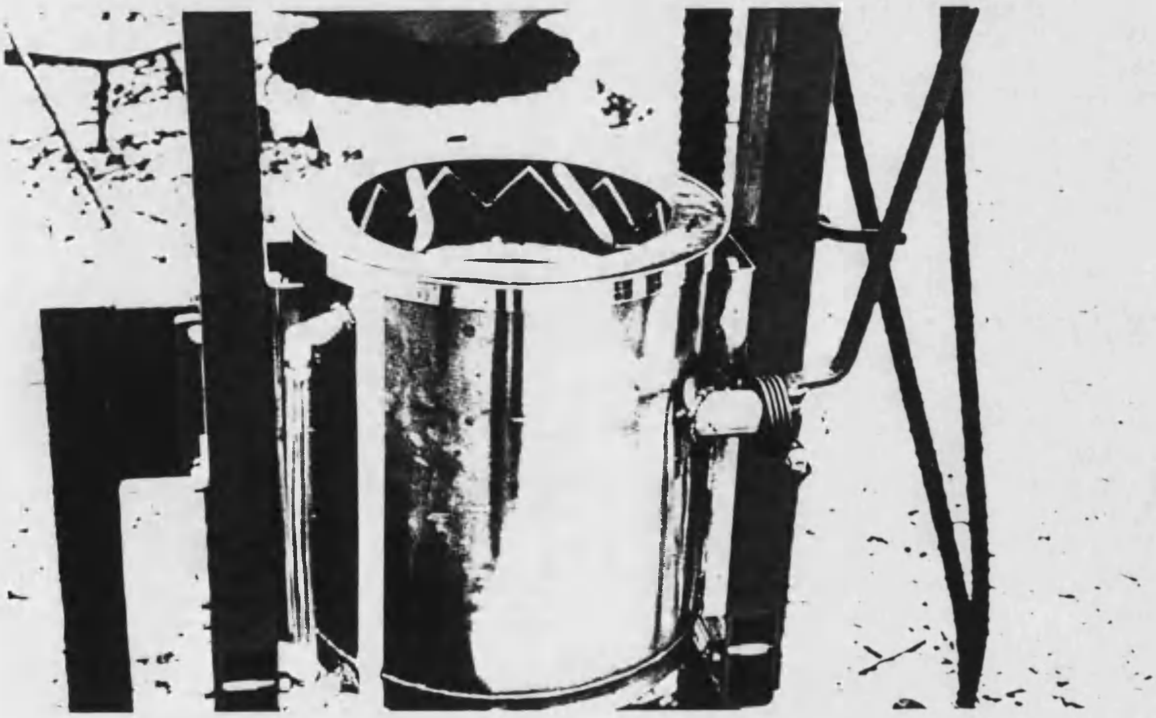

Fig.6 Captain Crunch

2.2.3.5 Direct Injection Closed System

A number of manufacturers have offered direct injection closed systems in the State for some years, but none of them have been sold in large numbers. The reasons offered to me in conversation are:-

a) long term reliability
b) cost
c) operator

I observed that most crop sprayers were fairly basic in design, not many used electronics for example. The sophistication of direct injection closed systems may be too great for many operators as they are mainly migrant workers from Mexico.

2.3 Reduction in Operator Safety

A number of regulations apply to the pesticide applicators and pest control advisers (PCA).

2.3.1 Operator Training

Operators who apply pesticides on other people's crops (called custom applicators) are required to pass the state examination. The operator has to study the basic textbook "The Safe and Effective Use of Pesticdes" by Marer, Flint and Stimmann, UCD Publication 3324, 1988 and then sit the General Test. The General Test is a 4 hour written paper using multi-choice answers; a specific Test, lasting 2 hours, also using the same format, is taken in the subject area that the applicator will be working.

Specific tests are held in the following subjects:

a) Application pest control - animals
b) Aquatic pest control
c) Forest pest control
d) Industrial-institutional pest control
e) Ornamental and turfgrass pest control
f) Right of way pest control
g) Seed treatment

The Test has been in existence since 1974, and carried out by the CDFA.

Farmers/growers who apply pesticides to their own land do not need to take the test. They must obtain a permit from the County Agricultural Commissioner to obtain restricted use products, eg Category One and some Category Two products; whilst obtaining this permit they will discuss the relevant safety procedures, etc with the County Agricultural Commissioner.

In the County of Monterey the controls are very strict and along with the farm size and cropping policy results in 99% of farmers using Custom Applicators.

Yellow County has much smaller farms, so most farmers carry out their own spraying.

2.3.2 Agricultural Pest Control Advisers (PCA)

Most of the pesticides applied in California are on the recommendation of an agricultural pest control adviser. The advice is legally binding. The adviser must have studied for a minimum of four years in college and passed the state examination. They must register with the County Agricultural Commissioner. The majority of Advisers, around 2500, work for the pesticide companies. There are another 500 who are independent.

2.3.3 Non-certified workers

A basic system has been devised to instruct the Spanish migrant worker in California. A cartoon/pictorial system is used which is easier to understand. A Matrix system is used to check off when a specific subject and product has been discussed. It should be noted that the farmers and workers do not sit any tests.

2.3.4 Protective Clothing

Protective clothing has been required since 1972, the Pesticide Protective Clothing Regulations apply to employees only. The label recommendation applies to all. Clean outer clothing must be provided by the employer, and laundry instructions given.

2.3.5 Permits

A permit is required before a restricted-use pestcide can be purchased or applied. This regulation applies to a qualified pesticide applicator and a farmer. The State and/or the County may reclassify a pesticide from general-purpose to restricted-use, or even ban a product.

All permits are obtained from the County Agricultural Commissioner. Permits are not required for general-use pesticides.

An application-restricted materials permit is shown in Appendix 5. The permit shows the pesticide, location, application rate, etc.

A notice of intent to apply restricted materials must be filed at the County Agricultural Commissioner's office at least 24 hours before applying the pesticide, see Appendix 6. The notice details product application rate, treatment area and environmental changes.

Within 7 days of applying a restricted product, a Pesticide Use Report must be submitted to the County Agricultural Commissioner. This report states the product, quantities used, when and where applied and who applied it, see Appendix 7.

2.3.6 Monitoring of health

Category One and Category Two pesticides, especially the Organo-phosphates and the Carbanates, need careful monitoring, especially with the Custom Applicators who are using them regularly. Monitoring, in the form of health checks, is required for

a) new employees, every 30th day for 3 months and
b) regular employees every 60 days.

Medical supervision is a financial arrangement between the custom applicator and the Doctor.

2.3.7 Incidents

The following rules apply to both the employer and employee. The Doctor reports all cases of suspected pesticide illness to the County Health Authority, that in turn passes it on to the County Agricultural Commissioner who investigates. This procedure is carried out by telephone, so it is very fast. The other method is via a report, a much slower method. If an injury occurs on a farm, it must be reported to the Bureau of Labour, which compile statistics, which in turn is picked up by Roy Rutz and the Department of Worker Safety which interprets the results.

2.3.8 Monitoring/Enforcing the Regulations

The County Agricultural Commissioners are responsible for enforcing the regulations, and monitoring pesticide use in a County. They ensure that pesticides are applied correctly and they can inspect any operation.

Appendix 8 shows the form that is used during a site inspection. The form details the specific task information:

eg: have the correct procedures been followed re permits
the type of application
field worker safety inspection
mixer/loader inspection
equipment and storage inspection

The Commissioner ticks a checklist to ensure that the regulations are being observed.

Appendix 9 shows the checklist that is used when inspecting the pesticide control records. The list details information about the records kept, the adviser records, training given and the pesticide storage.

The County Agricultural Commissioner has to enforce the regulations with the help of the Department of Food and Agriculture's Pesticide Enforcement Branch. The Branch comprises:-

four supervisors
four-six senior pesticide use specialists
four junior pesticide use specialists

The department can also carry out product quality tests on produce by sampling at wholesale and retail levels. They can take action such as destroying the whole crop if necessary. They also help the County Biologist to carry out pre-harvest checks on crops. The Commissioner may impose fines if the application is incorrect.

2.3.9 Penalties

An example of a fine for hand pouring instead of using a closed transfer system would be $500/violation.

Since 1986 the County Agricultural Commissioner and the CDFA Pesticide Enforcement Branch have been able to carry out an office hearing rather than a court hearing. This is much quicker. They can still give fines and take away the permit.

The Commissioner is a local political appointment, and so in rural areas he is relatively sympathetic to farmers compared with the Commissioners in the more urban areas. The urban fringes may want greater controls to appear on the label. However, the State has no power to dictate or change the content of any pesticide label, the Federal Government only can do that, and only through the use-permit process can the pesticide use be restricted at the County level.

2.4 Pesticide Containers

Pesticide containers can be categorised into two groups: single use disposable and returnable.

2.4.1 Single Use Disposable

Akesson (1989) estimates that nearly four million single use disposable containers are used every year, at least 75%, perhaps 90%, being plastic. Sizes vary from 2.5 gallons to 30 gallons.

2.4.2 Refillables

Refillables are delivered in various sizes from 2.5 to 10 gallons, for use in sprayers and mixing trucks to transfer pesticide from large 500-1500 gallon storage tanks to the sprayer. The 100-250 gallon, mini-bulk container is of growing interest. The mini-bulk container is owned by the pesticide manufacturer and returned to them when empty. The farmer/grower can meter the exact quantity required, via a small electric pump, into the sprayer. Any remnants in the tank can be returned to the distributor as the operator is unable to tamper with the container or its contents. A number of distributors will accept partially-filled returns.

Examples of mini-bulk containers are:-

1 ICI Satellite 110 mini-bulk system, 110 galls.
Construction of cross-linked polythene
Products: Eradicane 6.7E Sultan + Sultazine+
Eradicane Extra Eptam

2 Cyanamid 110 mini-bulk

Products:	Squadron	Tri-Scept
	Scepter	Prowl

3 Ciba-Geigy Farm-pak CS

Products: Dual (110 gall) Bicep (140 gall)

4 Monsanto

Product: Lariat

5 Stackable Series Chemical Tanks produce one piece polythene systems:
120, 185, 350 gallon
Essex Environmental Industries Inc

6 FMC

Product: Ammo Pounce

Both products are delivered in returnable stainless steel cannisters, 15 gallon and 30 gallon capacities.

2.4.3 <u>Pesticide Container Labels</u>

Regulations govern the format of pesticide labels and prescribe what information they must contain. The label regulations are very similar to those in the United Kingdom.

2.4.4 <u>The Laws affecting Container Rinsing</u>

The State laws are far more stringent than the EPA laws on Hazardous waste, eg: the EPA allows 10mm of pesticide to remain at the bottom of the container, whereas the State laws require that only one thousandth of one percent may remain. Triple rinsing is required and the farmer must check that a sample is occasionally taken to ensure that this rinsing is correct. The County Agricultural Commissioner can call and check. The Commissioners have no jurisdiction over containers as such, it is the hazardous waste that interests them.

Applicators are exempt from a permit providing the hazardous waste is treated within 90 days and that it stays on the site. A permit is required if the waste is to be moved to a waste disposal operation. It can only be moved by a Contract disposal operator who requires a permit and a manifest. The current thinking is to encourage waste treatment on the site where it was created.

2.4.5 Container Disposal

Rinsed cans can be placed in a landfill site, although they are normally crushed to reduce their size.

2.5 Reduction in Groundwater Contamination

A problem that has attracted a lot of interest is the presence of pesticides in groundwater. Public concern is increasing pressure upon legislators to produce new environmental legislation and regulations.

2.5.1 Californian legislation

It is illegal to dump hazardous waste into the soil. It must be taken to a special waste disposal contractor who can handle it (a permit is required to transport it to the contractor).

The pesticide operator must ensure all rinsates from his sprayer are disposed of correctly, either by spraying them on to the crop he is treating, or by placing them in an above ground store. Contaminated rinsewater is a recyclable material since it cannot be used for its original purpose. Contaminated water must therefore be treated as hazardous waste, and so a permit obtained.

A permit is also required if the waste is moved to a waste disposal contractor.

The current thinking is to encourage waste treatment on the site where it was created.

3 RECENT DEVELOPMENTS IN PESTICIDE APPLICATION

3.1 Closed System Sprayers

Closed system sprayers are used for all products in practice, as the custom applicators get used to handling pesticides through a transfer device. The following points were observed:

Probe systems:

i) ensure the probe is of a large enough bore so as not to limit the filling time, especially with high viscosity products.

ii) ensure the probe is covered or clean before extraction.

iii) variation in container openings results in problems of fitting. One type of probe destroys the fitting resulting in a problem if the container is half full and needs re-sealing.

3.1.1 Direct injection sprayers

During my discussions with applicators, they all realised the advantages of direct injection systems particularly the advantage of no tank rinsings compared with the problems arising in the State from groundwater pollution.

One particular operator, Soilserve of Salinas, who operates over 50 trailed crop sprayers, felt the cost involved in direct injection had limited the use of direct injection systems. He had devloped his own closed transfer system. The skill and attitude of ground crop sprayer operators limited the market for direct injection sprayers. Many operators were Mexicans with a poor command of English, let alone any technical skills. The majority of farmworkers in California are migrants.

I understand that the Mid-West is the main area of interest for direct injection closed systems where they are crop spraying as well as impregnating fertiliser. Fertiliser impregnation is of growing interest. The fertiliser is impregnated with pesticide as the spreader drives across the field. This combines two operators into one and reduces drift. It is mainly used with soil acting herbicides.

The injection of pesticides under pressure causes some concern with applicators, but this can be overcome by the use of quality piping and fittings, along with industrial rather than agricultural components.

3.2 Reducing Operator Contamination

Tightening of all safety laws concerning workers, perhaps basic toxicology lectures to all operators so that they appreciate the chronic dangers associated with pesticides.

The Crop Protection Advisers will really have to keep up to date on developments. Sources of information for the farmer/grower and adviser are seminars, publications, etc, and when they collect the permits.

The trend in California is for all pesticide recommendations and applications to be made by people with a licence.

The Government officals would like to see legislation applied to all applicators, better record-keeping to ensure that all pesticides used are recorded. At present only custom applicators have to inform the authorities of all the pesticides they use. Farmers have to inform the authorities if they use restricted-use products.

There is a trend in California for those outside Agriculture to provide the legislature with bills that receive a sympathetic hearing from the general public. An example of this is the Children's Food Safety and Pesticide Control Act, supported by Meryl Streep.

Government officials would like to see the development of:-

i) a crop log describing all applications carried out on that crop to accompany the crop through to market. Proposition 65 states that all pesticides used must be declared to the packager/processor of the food.

ii) Pesticide Management Zones (PMZ) - greater development. California leads the United States in laws for pesticide-use. Other States are following but it is costing the farmer more to conform with the legislation.

iii) worker legislation needs tightening with regard to applicator safety.

iv) A total reporting of all restricted pesticides being used. At present only custom applicators need report restricted products, not farmers/growers. The results at present: Alar - only 115lbs were used in the State last year! Researchers/scientists/food processors also need this information.

Next year field records must be kept for 3 years concerning all pesticides applied.

3.3 Pesticide Containers

i) Next year it will cost $400 to get a permit to carry pesticides in the farm truck. This will encourage farmers to get the distributor to deliver the pesticides.

ii) Not all products are available in mini-bulk containers, but there is a trend towards larger containers.

iii) According to an Californian Agricultural Aircraft Association survey, 36 pesticide packages were dissimilar in some manner. The major problem of size and opening variations has resulted in the use of can splitters, knives, etc.

iv) A number of companies recycle containers, provided they are rinsed three times. Metal cans are sent to Japan for recycling and the plastic cans are recycled in the US. Oil and pesticide cans are used.

v) The EPA Study. The Environmental Protection Agency has instigated a research contract with the Research Triangle Institute of North Carolina in the Spring of 1989, to collect background information on the spillage and splashing from the filling and use of pesticide containers, the amount of container waste and the mass of container materials (metal, paper, plastic) that has to be disposed of.

The information collected will be used as a basis for deciding the scope and format of Federal regulations.

3.4 Reducing Groundwater Pollution

Contamination of groundwater arises from a number of sources, careful application with correct disposal is most important. Most pollution has come from over-application, eg: Chemicals are introduced into the irrigation lines (Chemigation) and so a lot of waste can occur.

Application rates are very high on crops, eg: Citrus fruits are sprayed at 400-800 gallons per acre, traditionalists feel that if a little amount of spray will work, then a large amount will work better.

Hazardous material and waste

Hazardous material is a mixture of pesticide and water in the sprayer tank going to the field, whereas it is a hazardous waste if you are returning from the field. Different regulations apply in each case. The operator needs to empty his tank in the field or return to the special site at the farmyard. Most operators say they are going to another field to empty their contents. Hazardous waste can only be disposed of at two special sites in the State and there is a move to close these down. (Your containers of waste remain your property and responsibility at these sites!).

Anyone found discharging hazardous waste into groundwater is in serious trouble, facing fines if it is a violation, although accidental spillage is viewed quite differently. The State and regional water quality men inspect wells.

3.4.1 Monitoring

No official monitors as such, although enforcement officers will check the waste generators occasionally. Regional and State Water Quality Control Office monitor water for pesticide residues.

3.4.2 Tank Rinsing

Waste rinsing water at the farm must be contained, placed in containers/holding tanks. Some farmers/custom operators use a carbon filtration system, similar to the ICI Allman Sentinel to clean up their water rinsings. The treated water may then be used for future spray applications; this avoids the problems re hazardous waste, etc, although the cartridges need correct disposal.

During the early 1980s surface ponds could be created to allow the pesticide to evaporate, the soil became saturated with chemicals (Winterlin 1986). In 1984 it became illegal to have below ground stores. UCD created the soil bed which, providing it is above ground, is quite acceptable. A bin/tank holds pesticide and soil, the bacteria breaks down the chemicals, helped by sunlight.

There are two filtration systems that interest the State. A carbon filter system which was developed for water purification works well (similar to the Allman/ICI Sentinel), but the carbon filters block with algae too quickly. Ozone is now being tried to destroy the algae in the collection tanks, but this is creating new chemicals and making matters worse. The other problem is that the filters still have to be disposed of. There are two sites that will take hazardous waste such as those filters in the State, and these will close in 1990.

The second, more favoured filtration system, is the Concept 2000 which is a chemical oxidising system. Ozone and ultra violet light reduce the chemicals. Results show a reduction from 500/600 ppm down to zero. The Department are very keen on this system. The capital cost is $40,000.

3.4.3 Government research into Groundwater Pollution

Short term needs are:

i) accurate assessment

ii) cost effective reduction in overall contamination

3.4.3.1 The USDA Research Plan for Water Quality

The USDA launched a plan in January 1989 to improve water quality. It is hoped that the US Government will allocate $8-10 million in the October budget allocations (USDA 1989).

The outline of the plan is:-

1) Document sources and amounts of hazardous contaminants in groundwater, attributable to agriculture and forestry.

2) Develop new ways of analysing pesticide residues rapidly, inexpensively and reliably.

3) Develop new and modified crop and livestock production systems that substantially decrease the movement of potentially hazardous chemicals into groundwater.

4) Develop simple, inexpensive on-farm methods for disposing of pesticide containers and waste without contaminating groundwater.

5) Develop decision-aid systems to help technical and farm management specialists, agents and consultants to select, apply, and manage profitable and environmentally sound crop and livestock production practices.

6) Evaluate the economic, social and political impacts of the above points.

Example:
The pesticide disposal methods being researched are the use of ozone to fragment the pesticide, and soil micro-organisms to metabolise the fragments. Organisms and genes will be developed to enhance the breakdown rate of pesticides.

3.4.4 Training Programmes

A training programme has been developed at UC Davis for farmers, pest control advisers and extension service officers. A slide set and video outline the problems of pesticides and groundwater and show methods of reducing groundwater contamination.

3.4.5 Biochemical Degradation and Oxidation Systems

In an effort to reduce the amount of waste water there is concern that not enough water is being used to rinse sprayers or containers thoroughly. Simple plumbing and boom evacuation systems could result in minimal amounts of liquid remaining in the equipment.

Craigmill (1989) describes the problems associated with the removal of contaminated soils at the edge of sprayer wash-down concrete pads and under the concrete pads. Some years ago shallow evaporation pits were developed in California to evaporate pesticide/sprayer tank washing water, but these have recently been made illegal. (A number were found to be leaking into the soil). Research workers are at present considering:-

heavy liming to pH 10, leave a few weeks;
lime again, then add farmyard manure and blood meal to introduce micro organisms. During the first 3 months a very significant reduction in contamination occurs. It takes about 12 months to clean up the soil to an acceptable level.

3.5 Integrated Pest Management (IPM)

For a number of years there has been widespread concern regarding the use of pesticides, their effectiveness and their toxicity. Concern has been shown by all members of society.

The development of management systems which can predict and evaluate the economic effects on a crop, eliminate unnecessary applications, improve timeliness and consider environmental factors can result in reduction in pesticide use.

The Integrated Pest Management Program requires a greater understanding of crop husbandry and careful crop monitoring.

Federal and State aid has been available to develop IPM programs since 1979.

The goals of the University of California Integrated Pest Management Project (UCIPM 1989) are:

a) to reduce the pesticide load in the environment
b) to increase the predictability and thereby the effectiveness of the pest control techniques
c) to develop pest control programmes that are economically environmentally and socially acceptable
d) to marshall agencies and disciplines into integrated pest management programmes
e) to increase the utilisation of natural pest controls.

A substantial portion of the IPM project in California is directed at professional pest control advisers. There are seven IPM farm advisors working in the state. These advisers give workshops, demonstrations, talks and publications to the pest control adviser.

A recent survey (UCIPM 1989) showed that 75% of tomato growers stated that pest control advisers were their most frequently used source of information.

The IPM project has published 10 manuals, each detailing pest problems, diagnosis and monitoring, and management techniques. Crops covered are:

Tomatoes	Rice
Walnuts	Citrus
Cotton	Almonds
Lettuce	Alfalfa
Cole Crops	Potatoes

Future developments include:

i) a computerised information service, using a database
ii) many research programmes within the state studying crop and pest management
iii) Interactive video disc on Diagnostic systems

The 1988-89 budget allocation is:

Research	\$ 760,000
Computers and Meteorology	339,215
Implementation	476,133
Education and Publications	286,108
Internship Program	25,000
Director, Technical Committee, Operations, Projects	38,604
Adminstrative Office	59,964
	\$1,985,024

3.6 Aerial application of pesticides

Aerial spraying is highly regulated but is still extremely popular, some pilots flying at night when it is cooler. Care must be taken near built up areas, but there are vast tracts of open country where aerial spraying is still safe.

3.6.1 The California Agricultural Aircraft Association (CAAA)

There are approximately 180 commercial agricultural aviators in the State. 130 belong to the CAAA that apply 60% of pesticides. The CAAA are a professional organisation trying to promote the safe use of pesticides, and in so doing they hope to allay the fears of the general public.

The Agricultural Aviators have been confronted with increasing Government regulations, tightening environmental and workplace restrictions, along with increasing costs, more complex equipment and operating practices.

The CAAA responded to the pressures imposed upon them by developing an industry-wide professional training programme. The programme is aimed at developing safe pesticide application methods and handling techniques and is aimed at pilots, mixer loaders and flaggers. The programme has 39 standards, based upon safe operating procedures and the CAAA received a $350,000 grant from the CDFA to produce the programme. The training programme comprises a Standards Manual, its technical appendix, instructors training course handbook, three training manuals and eleven video tapes.

There is growing concern about custom applicators using county airports as their base. Pressure is being brought to bear to ensure that such sites are not creating any environmental damage.

4 CONCLUSIONS

1 Pressure, from outside Agriculture, is calling for greater constraints to be applied to pesticide use in California.

2 The Federal, State and County regulatory system in pesticide use appears to work in spite of the large number of departments involved.

3 The role of the County Agricultural Commissioners is extremely important. They are law enforcement officers, who besides monitoring and enforcing the law, inform the pesticide applicators of changes in the regulations.

4 There is a need to train all pesticide applicators thoroughly. The farmer and his employee need to be trained and examined in the same manner as the custom applicator is at present. Legislation is to be introduced to ensure that everyone who applies pesticides will be correctly trained.

5 All pesticide applicators using Category 1 and 2 products are very aware of the need for closed systems and the majority appear to use them properly. The closed system has become a matter of habit so a number of applicators use closed systems for all pesticide categories.

6 The closed system that uses a separate rinsing technique allows a much faster transfer process and, in some cases, a longer rinsing period.

7 The acceptance of closed systems will continue to increase as more products in Category Two and Three are brought under the closed transfer requirement.

8 Injection-type closed system sprayers have not yet developed fully in the State due to their high costs, accuracy with various pesticides and queries about their longevity. This type of equipment could provide the answer to the tank washing problem, and along with returnable containers such as the FMC 15 or 30 gallon models, would reduce groundwater contamination in one step.

9 Variation, in pesticide container size, shape and opening, exist as much in California as they do in the United Kingdom.

10 Burying containers in landfill sites is creating problems for future generations. Disposal is very expensive for Category One and Two pesticide containers.

11 Due to the shortage of space in landfill sites, pressure is growing to reduce the bulk of containers by crushing or pulverising.

12 If mini-bulk containers were adopted, many of the problems and expenses now faced by operators for rinsing and disposal would disappear. Mini-bulk containers would be welcomed by the operators, but as yet, not enough products are available.

13 To avoid severe penalties, the operators must ensure that pesticide, tank washings or container rinsings do not contaminate the soil. Applicators were very aware of pesticide contamination problems and were trying to practise good waste management.

14 The use of carbon filtration and ozone waste treatment plants for rinsates are not the answer. They are only a temporary solution; the problem needs preventing at source. Spent carbon filters are a potentially hazardous waste.

5 RECOMMENDATIONS

1 Ensure that there is no confusion between all concerned when drawing up regulations, particularly with waste sprayer washings. HSE, Water Authorities, Environmentalists and waste tip contractors must all work together.

2 Further research needs to be carried out on how the other member states of the EEC are addressing the problems outlined in this Report. Present and future regulations regarding containers and hazardous waste need to be monitored.

3 Develop more user-based education and training materials with courses in:
Basic toxicology, groundwater protection and
how to deal with the questioning public.
These courses could be part of a Continuing Education and Training programme.

4 It is recommended that a further study of the returnable container systems be made, with an evaluation of present and past uses as well as an economic analysis of each system.

5 Encourage the Agrochemical industry and its associations to have the foresight and courage to go to mini-bulk. A golden opportunity exists for everyone to improve the logistics of spraying, reduce waste contamination and improve their public image.

6 Further research, via survey of operators, should be carried out into exactly what happens to the containment and disposal of hazardous wastes.

7 The implementation of Closed Transfer Systems will greatly reduce operator contamination and environmental pollution. Brazelton and Akesson (1986) demonstrated how operator contamination was reduced, and operator experiences in California show that once a closed system is introduced on a sprayer, it is then used for all products. Guidelines or criteria must be laid down to advise on the design of closed transfer systems.

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APPENDIX 1 California's Agricultural Commodities

Commodity	Value ($1,000)	Acres Harvested (1,000 acres)	California's Share of U.S. Production (Percent)
Milk and Cream	2,084,731	-	12.7
Cattle and Calves	1,552,109	-	5.0
Grapes (all)	1,205,850	661.4	88.5
Cotton, Lint	992,479	1,140.9	20.3
Nursery Products	831,042	-	27.6
Hay, Alfalfa and Other	720,400	1,670.0	6.0
Flowers and Foliage	632,465	-	28.6
Almonds, Shelled	615,600	411.0	100.0
Lettuce	598,232	149.5	67.9
Tomatoes	560,728	242.6	77.8
Oranges (all)	422,520	172.9	32.1
Strawberries (all)	407,657	16.8	74.1
Chickens (all)	346,633	-	4.8
Eggs, Chicken	307,548	-	11.5
Walnuts	234,650	180.3	100.0
Sugar Beets	212,629	215.0	21.7
Broccoli	212,562	107.6	90.0
Rice	195,428	367.0	20.4
Turkeys	180,081	-	11.2
Prunes , Dried	166,440	75.4	100.0
Peaches (all)	163,864	53.7	60.5
Potatoes	159,649	51.0	4.9
Lemons	152,890	48.3	75.2
Cauliflower	147,156	51.1	75.1
Cantaloupe	146,798	85.1	not available
Celery	136,348	21.3	71.3
Mushrooms (all)	129,710	0.5	18.2
Onions	129,125	37.2	29.4
Carrots	125,952	43.0	50.1
Wheat	117,249	537.0	2.0
Sheep and Lambs	94,663	-	16.0
Avocados	93,686	75.0	91.8
Beans, Dry	84,186	168.0	11.9
Plums	75,361	39.2	82.1
Asparagus	74,746	39.7	not available
Apples	72,070	22.5	6.2
Corn for Grain	69,825	190.0	0.4
Nectarines	65,545	23.1	100.0
Pears (all)	64,794	23.1	38.7
Grapefruit	59,127	20.7	14.4
Pistachios	45,477	40.3	100.0
Alfalfa Seed	43,784	67.0	not available
Honeydew	43,754	20.6	77.1
Olives	41,991	31.5	100.0
Apricots	33,451	22.0	95.7
Barley	32,895	300.0	2.9
Hogs and Pigs	31,680	-	0.3
Cherries, Sweet	28,445	10.3	21.3
Sweetpotatoes	27,601	6.6	11.5
Safflower	26,962	106.0	not available

Source: Demment et al 1989

APPENDIX 2 Pesticide Toxicity Categories

HAZARD INDICATORS:	TOXICITY CATEGORIES I *DANGER*	 II *WARNING*	 III *CAUTION*	 IV *CAUTION*
Oral LD_{50}	Up to and including 50mg/kg	From 50 through 500 mg/kg	From 500 through 5000 mg/kg	Greater than 5000 mg/kg
Inhalation LC_{50}	Up to and including 0.2 mg/liter	From 0.2 through 2 mg/liter	From 2 through 20 mg/liter	Greater than 20 mg/liter
Dermal LD_{50}	Up to and including 200 mg/kg	From 200 through 2,000 mg/kg	From 2,000 through 20,000 mg/kg	Greater than 20,000 mg/kg
Eye effects	Corrosive; corneal opacity not reversible within 7 days	Corneal opacity reversible within 7 days; irritation persisting for 7 days	No corneal opacity; irritation reversible within 7 days	No irritation
Skin effects	Corrosive	Severe irritation at 72 hours	Moderate irritation at 72 hours	Mild or slight irritation at 72 hours

Category I Pesticides

Toxicity Category I pesticides (Figure 4-2) have an oral LD_{50} up to 50 mg/kg or a dermal LD_{50} up to 200 mg/kg. The signal word "Danger" appears on labels of pesticides in this category, along with the word "Poison" and a skull and crossbones. Category I pesticides are often the most hazardous because they are the most toxic. A few drops to a teaspoonful of a pesticide in this category could possibly cause death if taken orally. Less toxic pesticides may be included in toxicity Category I if there is a specific hazard, such as severe skin or eye injury, or a particular danger to the environment. For those, the signal word "Danger" appears on the label, but not the word "Poison" or the skull and crossbones.

Category II Pesticides

Toxicity Category II (Figure 4-3) includes pesticides that have an oral LD_{50} between 50 and 500 mg/kg or a dermal LD_{50} between 200 and 2000 mg/kg. The signal word "Warning" is used on labels of Category II materials, indicating they are moderately hazardous. Between 1 teaspoonful to 1 ounce (6 teaspoons) of chemical in this group would probably kill an adult.

Category III Pesticides

Toxicity Category III (Figure 4-4) pesticides have an oral LD_{50} over 500 mg/kg and a dermal LD_{50} greater than 2000 mg/kg. These pesticides have the signal word "Caution" printed on their labels, which indicates they may be slightly hazardous. Taken orally, over 1 ounce of pesticide in this category would probably be required to cause death in an adult. EPA regulations provide for a fourth group of pesticides, Category IV, which include materials that have an oral LD_{50} greater than 5000 mg/kg and a dermal LD_{50} greater than 20,000 mg/kg; these must be labeled with the signal word "Caution," so are often grouped with pesticides in Category III.

Source: Stimmann 1988

APPENDIX 3 Government Agencies

REGULATORY PROGRAM	WHO DOES IT	WHAT CAN IT DO?
Registration of pesticides	EPA, CDFA	Refuse or accept registration; suspend, cancel, or reregister pesticides.
Classification of pesticides	EPA, CDFA	EPA classifies pesticides as restricted or nonrestricted use in United States; CDFA may impose more stringent restrictions for California, based on special conditions existing in the state.
Permitting	CAC, CDFA	Issue, revoke, or refuse restricted-use pesticide permits (with use conditions) to growers, other private applicators, or certified applicators.
Licensing of commercial applicators, advisers, pesticide application businesses, dealers, and maintenance gardeners	CDFA*	Issue licenses and (in some cases) administer tests to applicants, including agents of businesses; revoke, suspend, or refuse licenses upon violation of pesticide laws.
Registering applicators and advisers, certifying private applicators	CAC	Register agricultural pest control businesses, aerial pest control operators, licensed pest control advisers, and maintenance gardeners. Through oral interview, certifies private applicators. Provide applicators and advisers with information on local pesticide use conditions. Inspect pesticide use records and pest control recommendations to verify proper pesticide use.

*In California, Structural Pest Control Operators are licensed by the Structural Pest Control Board, California Department of Consumer Affairs. Vector Control Certificates are issued by the Department of Health Services.

REGULATORY PROGRAM	WHO DOES IT	WHAT CAN IT DO?
Monitoring of pesticide residues on food and feed	USDA, CDFA, CAC**	Test food and feed for pesticide residues; quarantine or destroy illegally contaminated commodities; bring cases of violation to county district attorney or State Attorney General for prosecution.
Regulations governing pesticide use and worker safety	CDFA, CAC, DHS	General authority to regulate pest control operations, including restrictions on the time, place, and manner of application; various warning and enforcement powers.
Pesticide illness investigation	CDFA, CAC, DHS	Participate in pesticide illness investigations and in development of worker safety regulations.
Pesticide disposal and storage	CDFA, DHS, WRCB, WQCB, ARB, CAC	Regulates hazardous waste storage and disposal, pesticide container disposal sites, and water quality standards.
Protection of wildlife	EPA, FWS, DFG, CAC, CDFA	Investigate fish and wildlife losses. Identify and monitor endangered species. Restrict pesticide use to protect endangered species and other wildlife.
Citing or prosecuting violators	EPA, CDFA, CAC, SPCB, State Attorney General, Local District Attorneys	Agricultural commissioner may levy civil penalties with fines. CDFA may request Attorney General to take civil action. Attorney General may file accusation. CDFA may suspend or revoke applicator's certificate. CAC may suspend, revoke, or refuse permits and county registration.

**13 other state and 5 federal agencies monitor various parts of the environment for pesticides and other substances.

ARB: California Air Resources Board
CAC: County Agricultural Commissioner
CDFA: California Department of Food and Agriculture
DFG: California Department of Fish and Game
DHS: California Department of Health Services
EPA: U.S. Environmental Protection Agency
FWS: U.S. Fish and Wildlife Service
SPCB: Structural Pest Control Board California Department of Consumer Affairs
USDA: U.S. Department of Agriculture
WRCB: California Water Resources Control Board
WQCB: California Water Quality Control Board

Source: Stimmann 1988

CALIFORNIA PESTICIDE PERMIT REQUIREMENTS

A PESTICIDES DISPLAYING THE FOLLOWING STATEMENT ON THE PRODUCT CONTAINER

> RESTRICTED USE PESTICIDE
>
> FOR RETAIL SALE TO AND APPLICATION ONLY BY CERTIFIED APPLICATORS OR PERSONS UNDER THEIR DIRECT SUPERVISION

B CALIFORNIA RESTRICTED MATERIALS

TRADE NAMES ARE USED IN THE INTEREST OF SIMPLICITY. OTHER PRODUCTS WITH THE SAME COMPOUND AS AN ACTIVE INGREDIENT ARE ALSO SUBJECT TO THESE PERMIT REQUIREMENTS. REFER TO THE CALIFORNIA CODE OF REGULATIONS TITLE 3, SECTION 6400.

ACROLEIN FOR USE AS AN AQUATIC HERBICIDE
ALL DUST (EXCEPT THOSE PRODUCTS CONTAINING ONLY EXEMPT PESTICIDES)*
ANTIFOULING PAINTS OR COATINGS CONTAINING TRIBUTYLTIN*
ANY PESTICIDE USED PURSUANT TO A SECTION 18 EMERGENCY EXEMPTION
ALDRIN*
AVITROL
AZODRIN
BENTAZON FOR RICE
BHC*
BIDRIN
BOLERO
BROMOXYNIL
CADMIUM CONTAINING PESTICIDES*
CALCIUM CYANIDE
CARBON BISULFIDE
CARBON TETRACHLORIDE
CHLORDANE*
CHLOROPICRIN
COMPOUND 1080
DASANIT
DDD
DDT
DEF/FOLEX
DICAMBA
DIELDRIN*
DINOSEB
DI-SYSTON*
EDB
EDC
ENDRIN
ENDRIN TREATED CONIFER SEEDS
EPN
ETHION fuloeT
FURADAN
GALECRON/FUNDAL
GUTHION
HEPTACHLOR*
INORGANIC ARSENICALS OTHER THAN SODIUM ARSENITE*
LANNATE/NUDRIN*
LINDANE*
MCPA
METASYSTOX-R
METHYL BROMIDE
METHYL PARATHION
MERCURY CONTAINING PESTICIDES*
MERCURY TREATED SEEDS
MOCAP
MONITOR
NEMACUR
OMPA
ORDRAM
PARAQUAT
PARATHION
PHOSDRIN
PHOSPHAMIDON
PHOSTOXIN
PICLORAM
PROPANIL
PROPARGITE (OMITE/COMITE)
SEVIN*
SILVEX
SODIUM CYANIDE
SODIUM ARSENITE
STARLICIDE
STRYCHNINE*
SULFOTEPP
SYSTOX
SUPRACIDE
TELONE (DD)
TEMIK
TEPP
THIMET
THIODAN*
TOK
TORAK
TOXAPHENE*
TRITHION
ZINC PHOSPHIDE
2,4-D
2,4-DB
2,4-DP
2,4,5-T
2,4-DINITROPHENOL
4,6-DINITRO-O-CRESOL

PRIVATE APPLICATORS

GROWERS, NURSERYMEN AND OTHERS USING RESTRICTED PESTICIDES TO PRODUCE AGRICULTURAL COMMODITIES.

A PESTICIDES IN "A" ABOVE
PERMIT REQUIRED, NO EXEMPTIONS

B PESTICIDES IN "B" ABOVE
PERMIT REQUIRED, EXEMPTIONS APPLY UNLESS THE PESTICIDE IS IN "A" ABOVE

COMMERCIAL APPLICATORS

EVERYONE OTHER THAN PRIVATE APPLICATORS USING RESTRICTED PESTICIDES

QUALIFIED APPLICATOR LICENSEES
JOURNEYMAN PILOTS
VECTOR CONTROL TECHNICIANS
STRUCTURAL PEST CONTROL OPERATORS
QUALIFIED APPLICATOR CERTIFICATE HOLDERS

A PESTICIDES ONLY IN "A" ABOVE
NO PERMIT REQUIRED

B PESTICIDES IN "B" ABOVE
PERMIT REQUIRED, EXEMPTIONS APPLY

PERMIT EXEMPTIONS

* NO PERMIT REQUIRED FOR HOME, STRUCTURAL, INDUSTRIAL AND INSTITUTIONAL USES OF PESTICIDES MARKED WITH AN ASTERISK
- READY-TO-USE SYRUPS OR DRY BAITS CONTAINING SODIUM ARSENITE
- LESS THAN 25 POUNDS OF NON-RESTRICTED PESTICIDE DUST OR LARGER AMOUNTS FOR USE IN GREENHOUSES
- USE ON LIVESTOCK OR POULTRY
- LINDANE OR HEPTACLOR FOR SEED TREATMENT ONLY
- CARBARYL FORMULATED AS A BAIT
- ETHYLENE DICHLORIDE IN HOME USE FORMULATIONS ONLY
- PARAQUAT IN HOME USE FORMULATIONS ONLY
- MOCAP FOR OTHER THAN TURF USES
- GRANULAR FORMULATIONS OF FURADAN CONTAINING NOT MORE THAN 10% ACTIVE INGREDIENT
- ONE PINT OR POUND OF A PRODUCT CONTAINING A RESTICTED HERBICIDE PER 24 HOURS
- UP TO ONE GALLON OF READY-TO-USE SOLUTION CONTAINING AN HERBICIDE PER 24 HOURS
- UP TO 50 POUNDS OF A FERTILIZER OR AGRICULTURAL MINERAL WITH LESS THAN 10% ACTIVE HERBICIDE INGREDIENT PER 24 HOURS
- A WAX BLOCK IMPREGNATED WITH A RESTRICTED HERBICIDE
- ONE QUART OF DICAMBA PER 24 HOURS
- FLY BAIT CONTAINING 1% METHOMYL OR LESS

PE 33-013a (Rev. 12-88)

Source: CDFA

APPLICATION—RESTRICTED MATERIALS PERMIT

☐ FOR POSSESSION ONLY ☐ FOR POSSESSION AND USE

PERMITTEE ____________

PERMIT NO. ____________

PERMITTEE ADDRESS	CITY	ZIP	PHONE	TYPE OF PERMIT ☐ SEASONAL ☐ JOB	EXPIRATION DATE ____

☐ PRIVATE APPLICATOR ☐ STRUCTURAL PCO ☐ AGRICULTURAL PCO ☐ COMMERCIAL APPLICATOR

NOTICE OF INTENT REQUIRED ☐ MUST BE SUBMITTED AT LEAST ____ HOURS PRIOR TO APPLICATION. METHOD:

A. PESTICIDES/PESTS

1. ____	7. ____	13. ____
2. ____	8. ____	14. ____
3. ____	9. ____	15. ____
4. ____	10. ____	16. ____
5. ____	11. ____	17. ____
6. ____	12. ____	18. ____

B. LOCATION	SEC	TWN	RNG	MAP ID	COMMODITY	ACRES/ UNITS	PESTICIDES	PESTS	F*	M**	RATE	DILUTION/ VOLUME	APPL	DATE/ TIMING
1.														
2.														
3.														
4.														
5.														
6.														
7.														

PCO NAME	ADDRESS	PHONE	PCO NAME	ADDRESS	PHONE

C. JUSTIFICATION FOR NON-AG USE:

D. CONDITIONS:

I understand that this permit does not relieve me from liability for any damage to persons or property caused by the use of these pesticides. I waive any claim of liability or damages against the County Department of Agriculture based on the issuance of this permit. I further understand that this permit may be revoked when pesticides are used in conflict with the manufacturer's labeling or in violation of applicable laws, regulations and specific conditions of this permit. I authorize inspection at all reasonable times and whenever an emergency exists, by the Department of Food and Agriculture or the County Department of Agriculture of all areas treated or to be treated, storage facilities for pesticides or emptied containers and equipment used or to be used in the treatment.

*FORMULATION: L—LIQUID B—BAIT D—DUST F—FUMIGANT G—GRANULES WP—WETTABLE POWDER O—OTHER

**METHOD: A—AIR GR—GROUND F—FUMIGATION O—OTHER

PERMIT APPLICANT ____________ SIGNATURE ____________ TITLE ____________ DATE ____________

☐ RESTRICTED MATERIAL PERMIT IS HEREBY GRANTED FOR THE ABOVE MATERIALS. ☐ APPLICATION DENIED. BY ____________ DATE ____________

DISTRIBUTION: WHITE & YELLOW—COUNTY; PINK & GOLD—PERMITTEE 87 82647 PESTICIDE ENFORCEMENT BRANCH FORM 33-128 (REV. 7-87)

Source: CDFA

APPENDIX 6 Notice of Intent to Apply Restricted Materials

COUNTY ______
ADDRESS ______
COUNTY NO. ______

NOTICE OF INTENT TO APPLY
RESTRICTED MATERIALS

PERMIT NO. ______

PEST CONTROL OPERATOR	ADDRESS	PERMITTEE

LOCATION	SEC.	TWN.	RNG.	MAP ID	DATE OF APPLICATION

COMMODITY/SITE	ACRES/ UNITS	METHOD	PEST ( )

PESTICIDE	RATE	DILUTION/VOLUME	PESTICIDE	RATE	DILUTION/VOLUME
1.			4.		
2.			5.		
3.			6.		

ENVIRONMENTAL CHANGES: ______

TREATMENT AREA

SUBMITTED BY	DATE	TIME

REMARKS: ______

AGRICULTURAL COMMISSIONER: ______ DATE: ______ ☐ APPROVED ☐ DENIED

DISTRIBUTION, WHITE & YELLOW—COUNTY; PINK & GOLD—PERMITTEE PESTICIDE ENFORCEMENT BRANCH FORM 33-126 (REV. 7-87)

Source: CDFA

APPENDIX 7 Pesticide Use Report

STATE OF CALIFORNIA
DEPARTMENT OF FOOD AND AGRICULTURE
PESTICIDE ENFORCEMENT
33-126X (REV. 3/88)

PESTICIDE USE REPORT

1956480

COUNTY NO. 1 | SECTION 2 | TOWNSHIP N S 3 | RANGE E W 4 | BASE & MERIDIAN S H 5 M | APPLICATION METHOD AIR ☐ GROUND ☐ 6 OTHER ☐ | COMMODITY OR SITE TREATED 7 | APPLICATOR FIRM, (NAME AND ADDRESS) 8

MAP ID/DESCRIBE LOCATION 9

DATES APPLIED: PROPOSED / ACTUAL 10

ACRES OR UNITS TREATED: PROPOSED / ACTUAL 11

PERMITTEE/CUSTOMER 12

USE PERMIT NO. 13

APPLIED/SUPERVISED BY (PERSON'S NAME) 14

15 MFG. AND NAME OF PRODUCT APPLIED	16 REGISTRATION NO. FROM LABEL: INCLUDE ALPHA CODE	17 RATE	18 DILUTION/ VOLUME	19 TOTAL PRODUCT USED (CIRCLE UNIT OF MEASURE)	20 TARGET PEST(S)
	— — —			LB OZ PT QT GA	
	— — —			LB OZ PT QT GA	
	— — —			LB OZ PT QT GA	
	— — —			LB OZ PT QT GA	

ENVIRONMENTAL CHANGES/COMMENTS:

21 ____________________

NW	N	NE
W	TREATMENT AREA	E
SW	S	SE

26 ADJACENT CROPS, SCHOOLS, DWELLINGS, ETC.

SUBMITTED BY 22 | DATE 23 | TIME 24 | PCA NAME 25

RECEIVED BY 27 | BOX NO. 28 | DATE 29 | TIME 30 | 31 ☐ APPROVED ☐ DENIED

(2) CAC YELLOW *Submit to AGRICULTURAL COMMISSIONER within 7 DAYS after application.* 86 9701

Source: CDFA

______ COUNTY DEPARTMENT OF AGRICULTURE

33-021 (REV. 7/87) 87 82652

PESTICIDE USE MONITORING INSPECTIONS

FIRM/PERSON	APPLICATOR'S NAME	DATE	TIME STARTED
ADDRESS		EQUIPMENT NO.	TIME ENDING
PHONE NO.	PERMIT NO.	LICENSE NO.	

☐ Ag PCO ☐ Maint. Gardener ☐ Govt. Agency ☐ Qualified Applicator Certificate ☐ Private App.

BEEKEEPER NOTIFICATIONS REQUIRED ☐ YES ☐ NO

☐ Spray ☐ Granular ☐ Dust ☐ Fumigation ☐ Bait ☐ Other

RECOMMENDATION ☐ YES ☐ NO — ADVISER

OPERATOR OF PROPERTY/OWNER	LOCATION	WIND VELOCITY	DIRECTION
COMMODITY/SITE	ADJACENT ENVIRONMENT (N) (S) (E) (W)		

NAME OF PESTICIDE/PRODUCT	REGISTRATION NUMBER FROM LABEL	CAT.	REST. USE	DOSAGE/CONCENTRATION/VOL.

A. ☐ PRE-APPLICATION SITE INSPECTION

#	YES	NO	N/A	Ref. Section	
1				6434	Notice of Intent consistent with permit
2			///	6436	Proper target/pest (logical or expected)
3				6436	Proposed app. complies w/permit conditions
4			///	6436	Environ. cond. consistent w/permit and NOI
5				6436	Written recommendation reviewed
6			///	8556	Adequate methods for need to treat
7	///	//	///		Proposed app. approved ☐ YES ☐ NO
8					
9	///		///	Total	

B. ☐ APPLICATION INSPECTION ☐ AIR ☐ GROUND

#	YES	NO	N/A	Ref. Section	
1				11701	Licensed-business/individual-proper cat.
2				11732	Registered in County—Business/Pilot
3				6434	Notice of Intent submitted
4			///	12973	Complies with required labeling
5				14007	Complies with permit conditions
6			///	6600	Suitable methods/equip./manner/climate
7			///	6614	Protect. of nontarget prop./animals/persons
8				11909	Apprentice pilot supervised
9				2477(b)	Employee trained
10				2477(b)	Employee supervised (untrained persons)
11				6404-06	Restricted material use under supervision
12				2477(c)	Medical care posting
13			///	12973	Protective equipment worn
14				2480	Warning signs posted
15				6460-64	Drift cont. req./Phenoxy Herb. Specs.
16					
17	///		///	Total	

C. ☐ FIELD WORKER SAFETY INSPECTION

#	YES	NO	N/A	Ref. Section	
1			///	2479(a)	Handwashing facilities
2			///	2479(a)	Field supervisor trained
3			///	2479(c)	Reentry compliance/provisions
4			///	2479(a)	Emergency medical care arrangements
5					
6	///		///	Total	

D. ☐ MIX/LOAD INSPECTION

#	YES	NO	N/A	Ref. Section	
1				11701	Licensed/proper cat. business/individual
2				11732	Registered in county
3			///	12973	Complies with required labeling
4				2477(b)	Employee trained
5				2477(b)	Employee supervised (untrained persons)
6			///	12973	Protective equipment worn
7				2478(d)	Closed system used
8				2477(g)	Washing facil./Clothing—Cat. I & II
9				2477(c)	Medical care posting
10			///	6604	Accurate measuring devices
11			///	6670(b)	Containers secured and under control
12				6684	Empty containers rinsed at time of use
13				6404-06	Restricted mat. use under supervision
14	///		///	Total	

E. ☐ EQUIPMENT INSPECTION

#	YES	NO	N/A	Ref. Section	
1				11732	Equipment registered in County
2				6630	Equipment identified
3				2478(c)	Sight gauge
4				6606	Adequate agitation
5				6610	Backflow prevention
6				6460	Drift cont. noz. specs.-type/size/angle
7				12859	Service containers labeled
8			///	6600	Equip. in good repair/safe to operate
9					
10	///		///	Total	

F. ☐ PESTICIDE STORAGE SITE INSPECTION

#	YES	NO	N/A	Ref. Section	
1			///	6672(b)	Locked enclosure
2				6674	Storage area posted
3				6684	Containers properly rinsed
4			///	6676	Pesticides labeled
5			///	6680	Pesticides stored in proper containers
6				6412	Possession permit for pesticides stored
7					
8	///		///	Total	

REMARKS:

Signature of Enforcement Officer	Acknowledgement of Inspection
Follow-up Required ☐ YES ☐ NO — Notice of Violation Issued ☐ YES ☐ NO # ______	The Noncompliance Items Noted Above Are Violations and Must Be Corrected By ______

Distribution: Original—County 1st Copy—Inspector 2nd Copy—Person/Firm Inspected

Source: CDFA

APPENDIX 9 Pest Control Records Inspections

________________ COUNTY DEPARTMENT OF AGRICULTURE

(33-022 REV. 7/87)

PEST CONTROL RECORDS INSPECTIONS

FIRM/PERSON	PERMIT NO.	DATE
ADDRESS	PHONE NO.	TIME START
LOCATION		TIME END

☐ Ag. PCO ☐ Maint. Gardener ☐ Govt. Agency ☐ Qualified Applicator Certificate ☐ Private App. ☐ Other

COMPLIANCE #	YES	NO	N/A	Ref. Section	A. ☐ OPERATOR BUSINESS RECORD AUDIT ☐ Main ☐ Branch
1				11701/32	Licensed registered, No. ______
2			///	11702	Work supervised by qualified person
3				11901	Pilots hold valid certificate/registered
4			///	6438	Application records maintained 2 years
5				12004	Written recommendations retained 1 year
6			///	6438-40	Use reports complete submitted
7				6632	Valid permits for restricted materials
8					
9	///		///	Total	

COMPLIANCE #	YES	NO	N/A	Ref. Section	B. ☐ DEALER RECORD AUDIT (No. Records Audited______) ☐ Main ☐ Branch
1			///	12101	Licensed, No. ______
2			///	6560	Designated agent; Name ______
3				6562	Sales records maintained 2 years
4				6568	Permit statement of R.M. sales (1 year)
5				6562	Recommendation statement for each sale
6				6564	Appropriate products sold
7					
8					
9	///		///	Total	

COMPLIANCE #	YES	NO	N/A	Ref. Section	C. ☐ ADVISER RECORD AUDIT (No. Records Audited______)
1			///	12001-2	Licensed registered, No. ______
2				12054	Recommendations in proper categories
3				12003	Contains required information
4				6556	Cert. of alternatives/mitigation measures
5				6556	Criteria for recommended treatment
6				12971	Complies with labeling
7				12004	Recommendations retained 1 year
8				12003	Copies to grower/applic./dealer
9					
10					
11	///		///	Total	

COMPLIANCE #	YES	NO	N/A	Ref. Section	D. ☐ CERTIFIED APPLICATOR RECORD AUDIT
1			///	6404	Certified person
2				6530	Proper categories (______)
3			///	6440	Use reports submitted
4			///	6412	Valid permit for restricted materials
5					
6	///		///	Total	

COMPLIANCE #	YES	NO	N/A	Ref. Section	E. ☐ EMPLOYER HEADQUARTERS INSPECTION
	///	///	///	2477(b)	Training Program
1					—Required topics covered
2					—Training prior to handling
3					—Training records available/complete
4				2744(d)	Baseline (30 hrs./30 days I/II-op/carb.)
5				2744(d)	Written evidence of med. supervision
6				2744(d)	Test results/recomm. available (3 yrs.)
7				2477(f)	Change area (30 hrs./30 days I/II)
8				6410	Safety series available to employees
9				2481	Application records (Reentry > 4 hrs.)
10					
11	///		///	Total	

COMPLIANCE #	YES	NO	N/A	Ref. Section	F. ☐ PESTICIDE STORAGE SITE INSPECTION
1			///	6672(b)	Locked enclosure
2				6674	Storage area posted
3				6684	Containers properly rinsed
4			///	6676	Pesticides labeled
5			///	6680	Pesticides stored in proper containers
6				6412	Possession permit for pesticides stored
7					
8					
9					
10					
11	///		///	Total	

REMARKS:

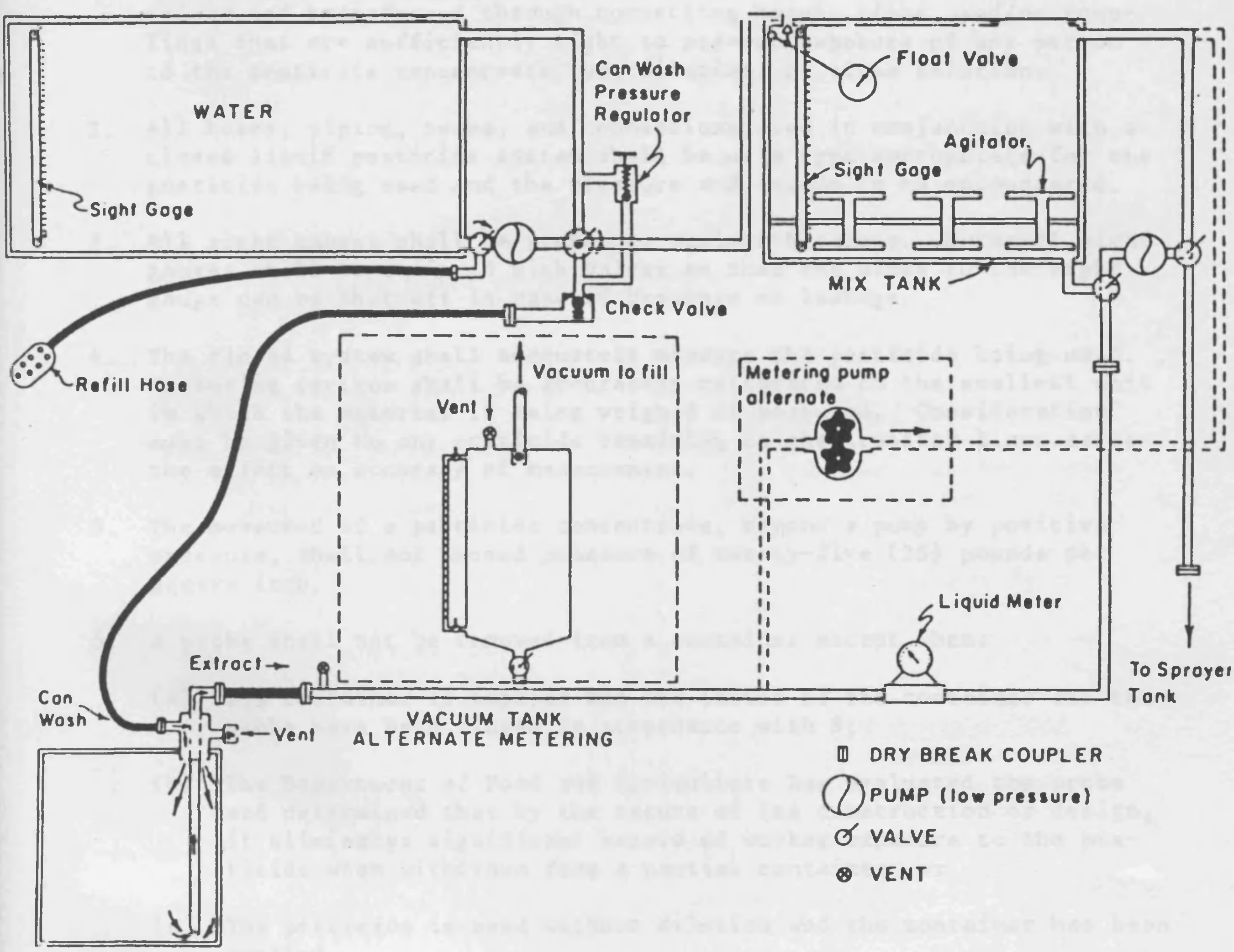
Signature of Enforcement Officer	Acknowledgement of Inspection
Follow-up Required ☐ YES ☐ NO / Notice of Violation Issued ☐ YES ☐ NO # ______	The Noncompliance Items Noted Above Are Violations And Must Be Corrected By ______

Distribution Original—County 1st Copy—Inspector 2nd Copy—Person Firm Inspected

87 82649

Source: CDFA

APPENDIX 10 Schematic of a Closed System



Source: Brazelton and Akesson 1986

STATE OF CALIFORNIA
DEPARTMENT OF FOOD AND AGRICULTURE

CRITERIA FOR CLOSED LIQUID PESTICIDE SYSTEMS

1. The liquid pesticide shall be removed from its original shipping container and transferred through connecting hoses, pipes, and/or couplings that are sufficiently tight to prevent exposure of any person to the pesticide concentrate, use dilution, or rinse solution.

2. All hoses, piping, tanks, and connections used in conjunction with a closed liquid pesticide system shall be of a type appropriate for the pesticide being used and the pressure and vacuum to be encountered.

3. All sight gauges shall be protected against breakage. External sight gauges shall be equipped with valves so that the pipes to the sight gauge can be shut off in case of breakage or leakage.

4. The closed system shall adequately measure the pesticide being used. Measuring devices shall be accurately calibrated to the smallest unit in which the material is being weighed or measured. Consideration must be given to any pesticide remaining in the transfer lines as to the effect on accuracy of measurement.

5. The movement of a pesticide concentrate, beyond a pump by positive pressure, shall not exceed pressure of twenty-five (25) pounds per square inch.

6. A probe shall not be removed from a container except when:

   (a) The container is emptied and the inside of the container and the probe have been rinsed in accordance with 8;

   (b) The Department of Food and Agriculture has evaluated the probe and determined that by the nature of its construction or design, it eliminates significant hazard of worker exposure to the pesticide when withdrawn from a partial container; or

   (c) The pesticide is used without dilution and the container has been emptied.

7. Shut off devices shall be installed on the exit end of all hoses and at all disconnect points to prevent leakage of pesticide when the transfer is stopped and the hose removed or disconnected.

   (a) If the hose carried pesticide concentrate and has not been rinsed in accordance with 8, a dry coupler that will minimize pesticide drippage to not more than two milliliters per disconnect shall be installed at the disconnect point..

   (b) If the hose carried a pesticide use dilution or rinse solution, a reversing action pump or a similar system that will empty the hose and eliminate dripping of liquid from the end of the hose may be used as an alternative to a shut off device.

8. When the pesticide is to be diluted for use, the closed system shall provide for adequate rinsing of containers that have held less than 60 gallons of a liquid pesticide. Rinsing shall be done with a medium, such as water, that contains no pesticide.

   (a) The rinsing system shall be capable of spray rinsing the inner surfaces of the container and the rinse solution shall go into the pesticide mix tank or applicator vehicle via the closed system. The system shall be capable of adequately rinsing the probe (if used) and all hoses, measuring devices, etc.

   (b) A minimum of 15 pounds pressure per square inch shall be used for rinsing.

   (c) The rinsing shall be continued until a minimum of one-half of the container volume or 10 gallons, whichever is less, of rinse medium has been used.

   (d) The rinse solution shall be removed from the pesticide container concurrent with introduction of the rinse medium.

   (e) Pesticide containers shall be protected against excessive pressure during the container rinse operation. The maximum container pressure shall not exceed five (5) pounds pressure per square inch.

9. Each commercially produced closed system or component to be used with a closed system shall be sold with a complete set of instructions on its operation. These instructions shall consist of a functional operating manual and a decal and/or system of decals placed on the system covering the basic operation.

   The instructions shall include specific directions for cleaning and maintenance of the system on a scheduled basis. The instructions shall also describe any restrictions or limitations relating to the system such as pesticides that are incompatible with materials used in the construction of the system, types (or sizes) of containers or closures that cannot be handled by the system, any limits on ability to correct for over measurement of a pesticide, or special procedures or limitations on the ability of the system to deal with partial containers.

This criteria does not preclude closed systems utilizing procedures other than those outlined above. Questions concerning the ability of other procedures to meet California's closed system requirement may be directed to:

Department of Food and Agriculture
Pesticide Enforcement
1220 N Street, Room A-170
Sacramento, California 95814
(916) 322-5032

Source: CDFA

This is a list of suppliers of available closed systems which have been observed by the Department of Food and Agriculture and appear to meet the Director's closed system criteria.

ALL PRICE INFORMATION IS SUBJECT TO CHANGE AND IS FOR REFERENCE ONLY

The following "codes" indicate what sizes of containers each system is compatible with, what action the system has upon the container or its closure, and any limitations the system may have.

1. All containers
2. One gallon containers
3. Containers except glass
4. Up to five gallons
5. Five gallon metal.
6. One gallon up to 30 gallons
7. One gallon up to 55 gallons
8. Five gallons up to 55 gallons
9. Wettable powders and soluble bags
10. 30 and 55 gallon containers
11. 15 gallon mini-bulk
12. 30 gallon and larger bulk containers

a. destroys closure
b. cannot be removed from partial container
c. leaves closure intact
d. may be removed from partial container
e. destroys container
f. reusable container
g. use with undiluted material

FIRM :

AMC/Wilbur-Ellis
4106 S. Cedar Ave.
Fresno, CA 93725- 2703
(209) 485-1662
Code: 6, c, d

Blackwelders
"Pestran II"
P.O. Box 127
Rio Vista, CA 94571
(707) 374-6441
Code: 8, b

Cherlor Mfg. Co., Inc.
"Chemprobe" "Chemsure" "Chemrinse" "Maxi-load"
P.O. Box 2174
Salinas, CA 93902
(408) 422-5477
Code: 1, c, d "Chemprobe"
1, c, d "Chemsure and Chemrinse"
(especially for measuring small amounts)
4, c, d "Maxi-load"
(especially for commercial operators)

Custom Farm Systems of Arizona
"Goodwin Can Opener"
P.O. Box 338
Stanfield, AZ
(602) 424-3322
Code: 3, 4, e

D and D Closed Transfer System
P.O. Box 997
Blythe, CA 92225
(619) 922-8644
Code: 3, 6, e

Load Safe Systems, Inc.
P.O. Box 421
Heber Springs, AR 72543
(501) 362-8404 or 362-8238
Code: 7, 9, e
12, f

Mazzei Injector Corporation
Route 5, Box 453
Bakersfield, CA 93307
(805) 845-2076 or (209) 431-3059
Codes: 3, 4, c, d "Quick load"
10, c, d "Drum probe"

Mid-Continent Aircraft Corp.
"Captain Crunch"
Planemate Division
Drawer L
Hayti, MO 63851
Code: 3, 5, e

Protect-O-Mfg. Co.
Star Route, Box 8337
Redmond, OR
(503) 548-5446 OR 382-6886
Code: 3, 7 destroys closures on small (1 gal./5 gal.) containers, does not destroy on larger drums

S & R Specialty Equipment Co.
Strong Steel Fabricating and Welding
P.O. Box 505
Corcoran, CA 93212
(209) 992-4191
Code: 7, a, b

J. E. Soares, Inc.
Specialty Steel Fabrication
"Goodwin Can Opener"
7093 Dry Creek Road
Belgrade, MT 59714
(406) 388-6069
Code: 3, 4, e

Termco, Inc.
"Calibrator"
9308 G Street
Oakland, CA 94603
(415) 638-3654 or 487-1766
Code: 7, b

Sciencо Inc.
"DD-6"
5558 Federal
Memphis, TN 38118
(901) 365-8804
Code: 12, f

Advanced Plant Mgmt.
"APM Chemical Tree Injector"
P.O. Box 99
Paso Robles, CA 93447
(805) 466-7517 or 238-0127
Code: 2, g

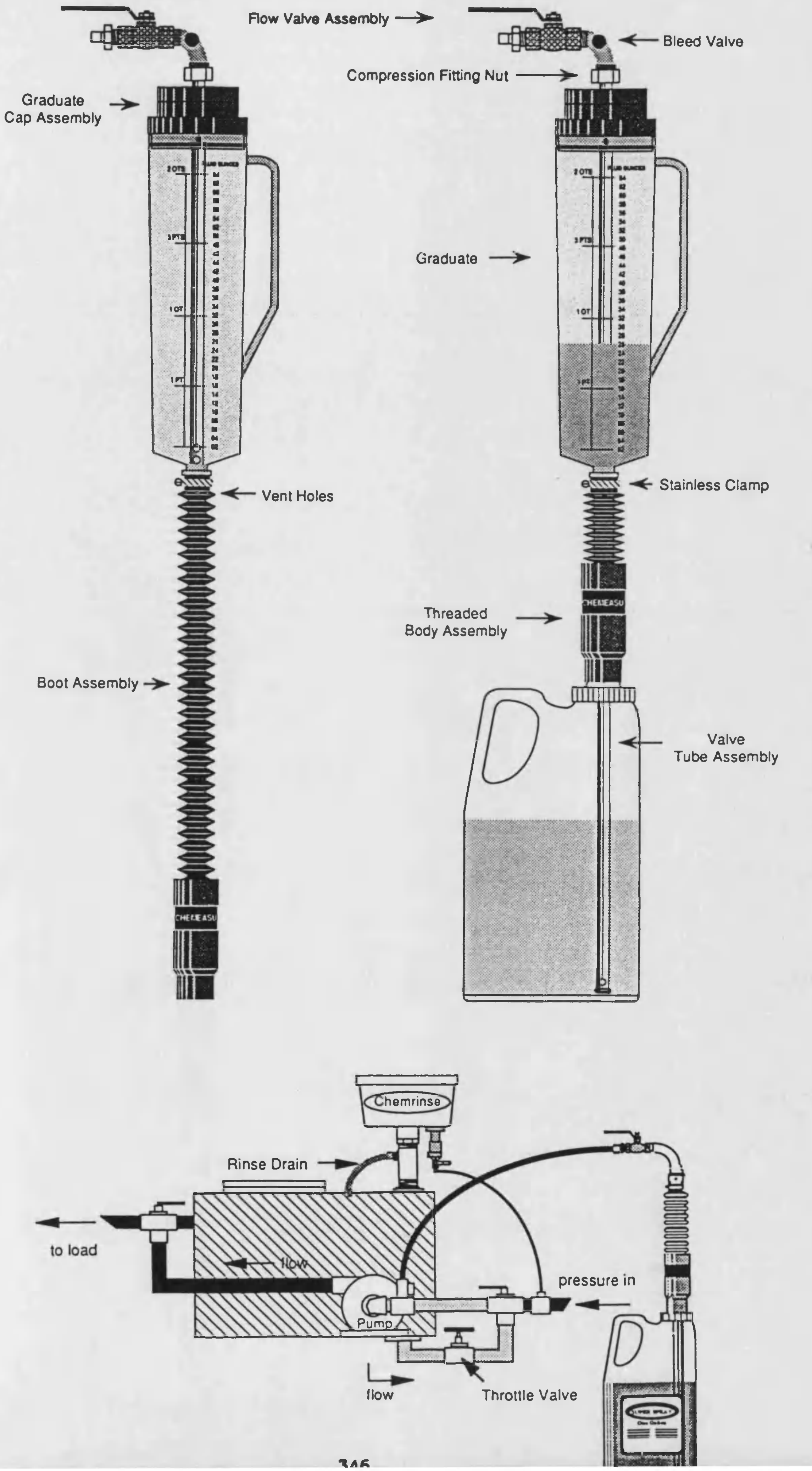
Arbor Chem. Products Co.
"CM 3 & CM 6 Tree Injectors"
P.O. Box 1567
Fort Washington, PA 19034
1-800-874-0442
Code: 2, g

ICI Americas
"Precision Closed System Pump"
4543 Tumbleweed Lane
Paso Robles, CA 93446
(805) 227-6632
Code: 4, c, d (Gramoxone & Devrinol

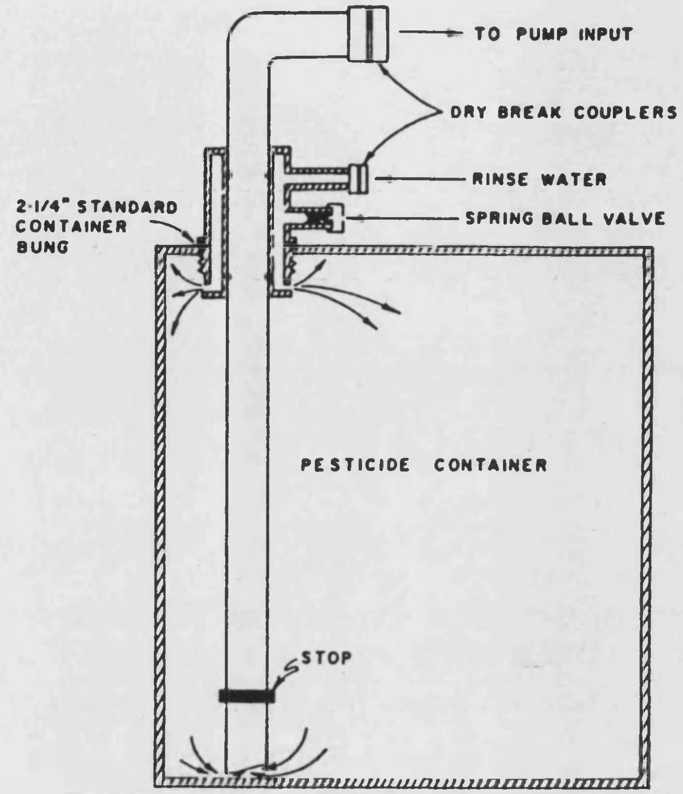
Col-Fab Enterprise
"Col-Fab Closed System"
440 N. Orangewood
Fresno, CA 93727
(209) 456-8672 or 884-2428
Codes: 5, a, b "Col-Fab Probe"
11, d, f "Mini-Bulk"

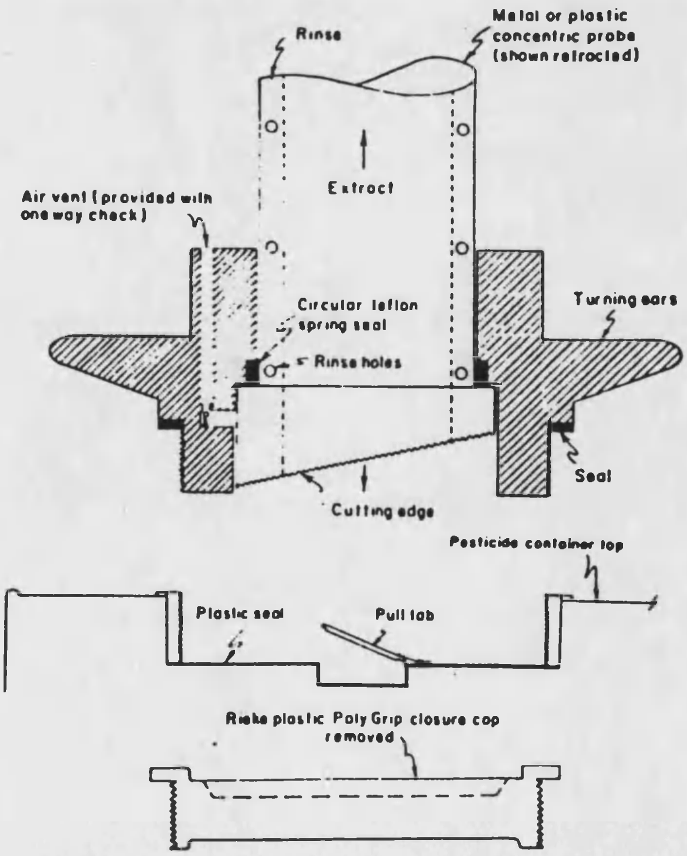
Source: CDFA

APPENDIX 13 The Cherlor Mfg Closed Transfer and Rinsing System



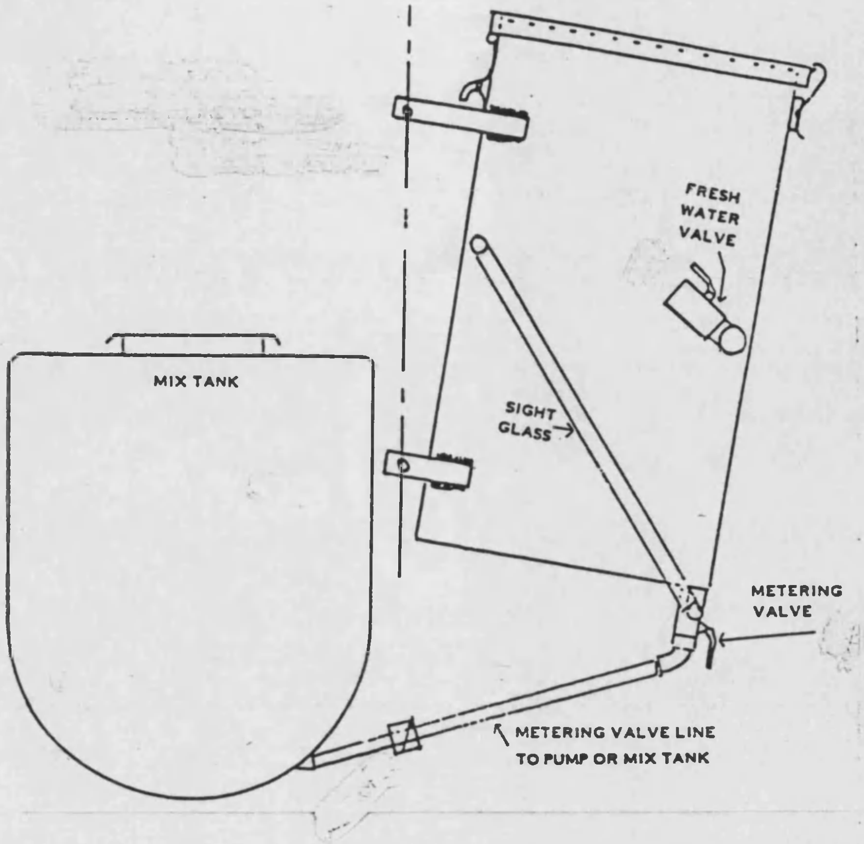
The Protect-o-Manufacturing Co Probe

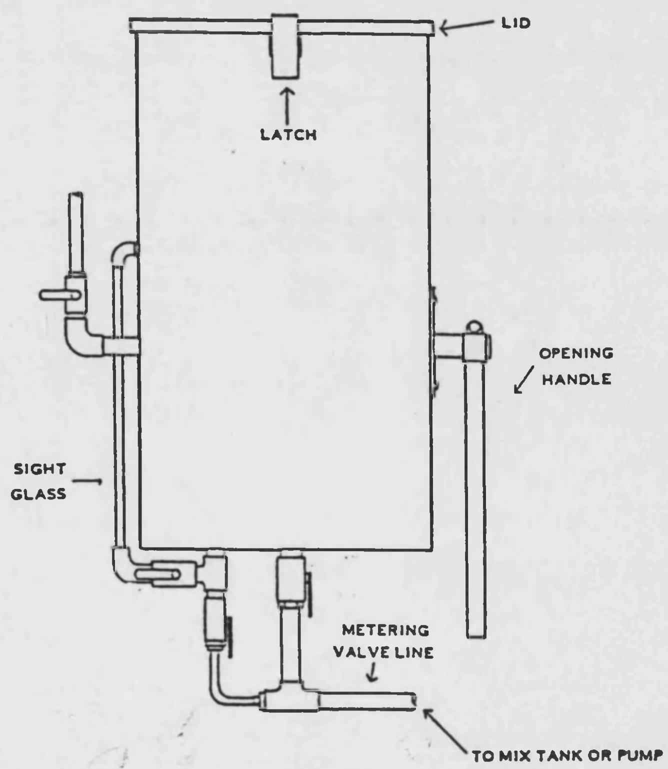


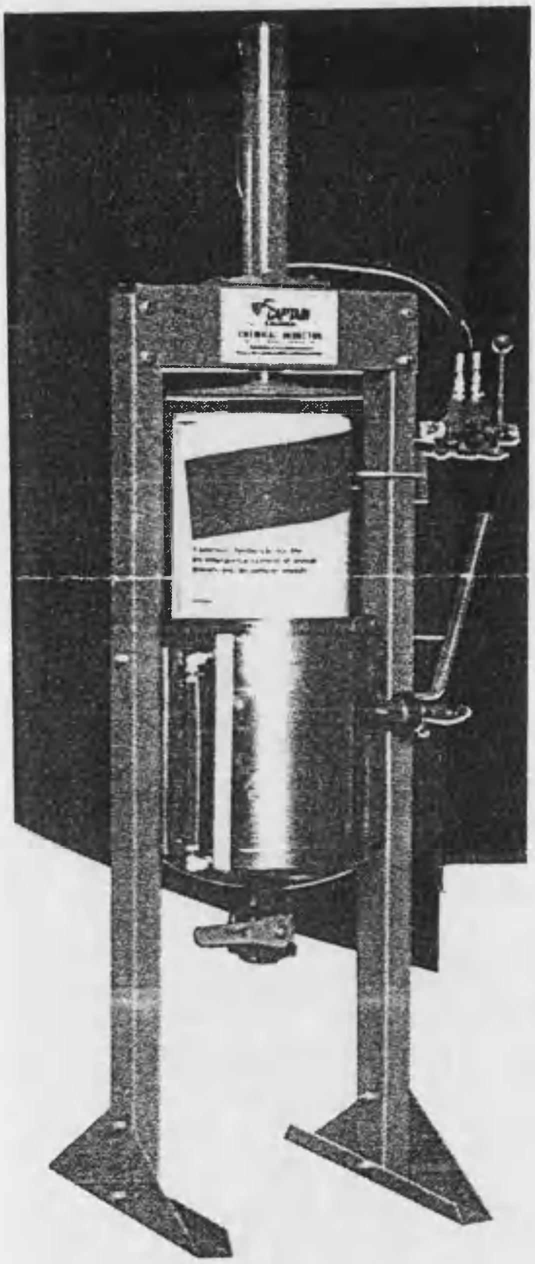


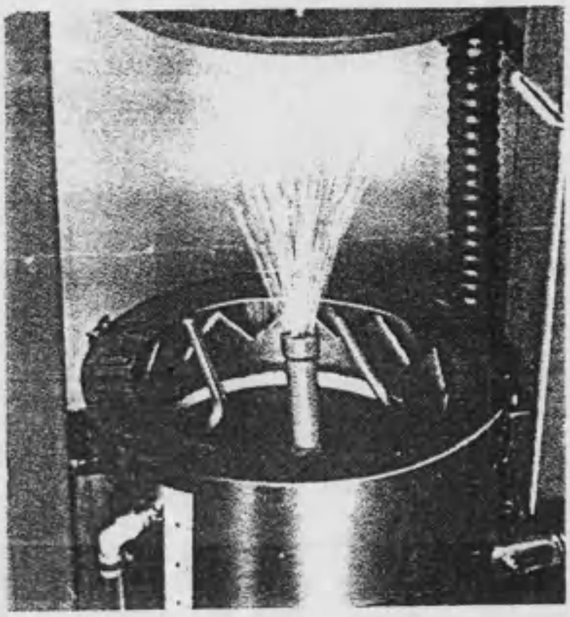
Source: Brazelton and Akesson 1986

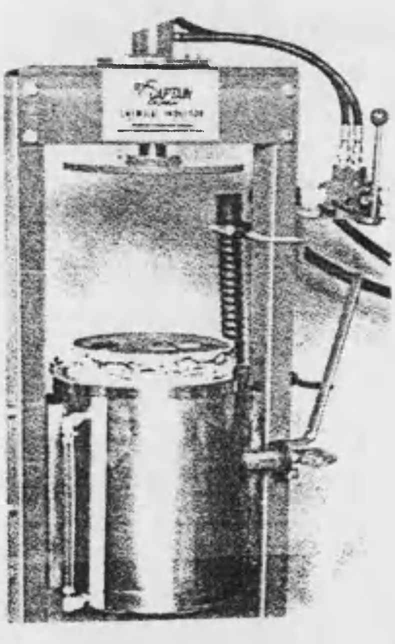
APPENDIX 15 The Goodwin Can Opener

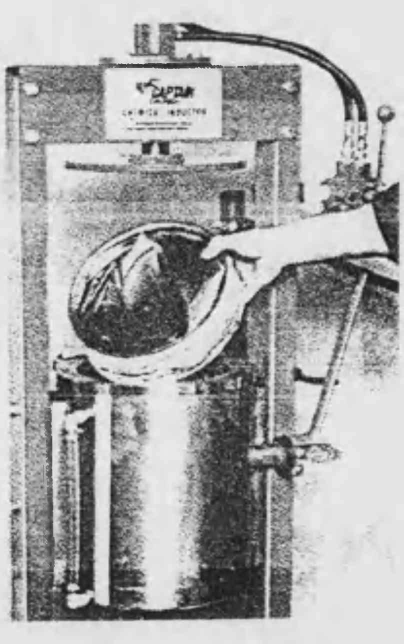












APPENDIX D

<u>PREVIOUSLY PUBLISHED PAPERS</u>

Landers, A.J.(1990). Engineering control methods - the development of direct injection sprayers. In: COSSH - Engineering Controls in Agriculture. Stoneleigh, September 1990. Bootle: Health and Safety Executive

COSHH - Engineering Controls in Agriculture
HSE Conference, 27 September 1990

Engineering Control Methods - the development of direct injection sprayers

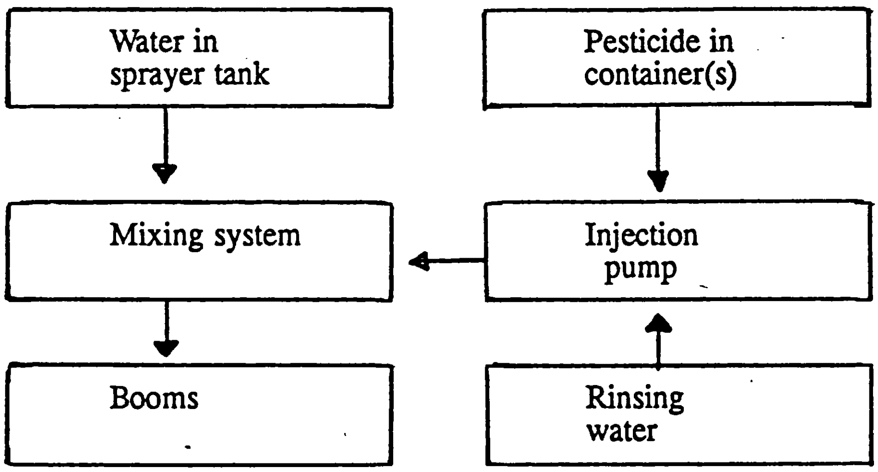
Andrew Landers
Senior Lecturer in Agricultural Mechanisation

Royal Agricultural College
Cirencester, Glos GL7 6JS

Current UK and European Community legislation has prompted significant moves towards safer practices for storing, handling and applying pesticides. The Control of Substances Hazardous to Health Act (COSHH) enacted in October 1989, requires the exposure to hazardous substances hazardous to health to be either prevented or, where this is not reasonably practicable, adequately controlled. Regulation 7 (2) requires that prevention or control is secured by measures other than the provision of personal protective equipment. Control must, so far as is reasonably practicable, be by engineering control methods. Increased awareness by the general public about environmental pollution has also increased the need for farmers and equipment manufacturers to examine their methods of pesticide usage.

The application of electronics to spray equipment has resulted in the development of a "dosing" system that injects pesticide directly into the spraylines of a conventional crop sprayer. This removes the need to pre-mix chemicals and means that no pesticide is ever placed in the sprayer's water tank. This technique not only helps the operator to carry out the spraying task safely, it also ensures accurate safe metering of the concentrated product. Thus closed direct injection sprayers have considerable financial benefits, particularly in savings in operator time and reducing product wastage. *(Figure 1 shows the basic concept of a direct injection sprayer)*

Fig 1: The basic concept of a direct injection sprayer



Disposal of dilute waste and washings

Under part one of the Control of Pollution Act (1974) it is an offence to abandon, or dispose of waste which is poisonous, noxious, or polluting on any land where it is likely to give rise to an environmental hazard. Under the Water Act (1989) it is an offence to cause, or knowingly permit, any poisonous, noxious or polluting matter to enter controlled waters. Today's farmer must be extremely careful when washing out a crop sprayer and the use of direct injection sprayers will minimise the risk of environmental pollution because the main tank contains only clean water.

The Development of Injection Closed Systems.

Closed Systems are currently being developed in Europe, North America and Australia. Much of the development has taken place in the countries where legislation against pollution of the environment is placing increasing restrictions on farmers and growers.

The AgriFutura Dose 2000

Developed in Sweden, the Agrifutura Dose 2000 is available in kit form and comprises containers, a pump with mounting unit and a mixing chamber. These components can be fitted easily to any conventional field sprayer.

The operator can select the required dose rate on a control box mounted in the cab. A micro-processor controlled ceramic piston pump delivers the pesticide concentrate from a container into a mixing chamber. After thorough mixing with clean water the solution is pumped to the boom nozzles.

Pesticide Containers.

Thirty litre capacity containers are filled with pesticide from the manufacturer's container by means of an electrically controlled filling station. A probe connected via a pipe to a dosing pump reaches down to a pre-formed well in the base of the container. This ensures that no pesticide is left in the bottom. The filling operation can be carried out at the chemical store.

The Dosing Pump

A ceramic piston pump operates in a stainless steel cylinder. Both these materials are relatively durable when exposed to concentrated chemicals. All seals are made of PTFE. The piston stroke length is altered by a stepper motor, controlled by the in-cab controller. Power input is from the tractor PTO, and the piston pump is only switched on when water flow occurs. This is detected by a flow meter near the main control valve.

The Mixing Chamber

Pesticide is delivered by pipes to the mixing chamber, situated between the water pressure regulating valve and the boom selection valves. Here it joins clean water from the sprayer tank. The mixing chamber is large enough to even out the pulsing of the piston pump, but small enough to prevent a time delay when changing dose levels. To minimise the time delay, the best place for the mixing chamber is at the rear of the sprayer, next to the booms. The mixed pesticide/water solution passes to the boom nozzles via the boom manifold valves.

In-Cab Control Box

The in-cab controller panel displays the following features:

- Dose level, (one of four). Dose level adjustment is made by simply switching between the various settings.

- Pumps 1,2,3. The operator can use one or all of these pumps to inject compatible products as, and when, required.

- Calibration. A calibration factor can be entered to take account of different viscosities of products. A simple test can be run and new settings inserted at the press of a button.

- Distance Remaining. This tells the operator at what distance he has to change from pesticide to rinsing water to decontaminate the sprayer before leaving the field.

- Alarms. A number of audio-visual alarms alert the driver when pesticide and water are running low, hose leaks, or other system errors.

The Dose 2000 has been evaluated, by the author in different crops, using pesticides at various rates, at the Royal Agricultural College's farms since 1988.

The Walsh CCI-2000

Developed in the USA in the mid 1980's, the Walsh CCI-2000 has been imported and modified in the UK. The system comprises of individual cone bottomed pesticide tanks from which up to three different pesticides can be applied. The tanks are connected to peristaltic tube pumps which meter the pesticide into the induction manifold where it joins the clean water from the sprayer water tank. The pumps are driven by 12 volt variable speed electric motors. By varying the motor speed and tube size, the pumps can inject pesticide within a wide range of application rates.

The pesticide solution passes through the stainless steel return manifold, through the sprayer pump and into the spray manifold. Boom control valves then allow it to pass to the booms. If a boom section has been switched off the diluent returns to the manifold. The use of a butterfly control valve controls the amount sprayed in relation to forward speed. Non return valves ensure that no pesticide goes into the water tank.

The in-cab control regulates pump output; compensating for changes in speed and volume. It can control up to three pumps individually or together. The area sprayed and the amount applied is also measured. An increase/decrease button allows the pump setting to be overridden at 5% intervals. This is useful for adjusting dose rate to match changing levels of infestation within a field or for spot treatment.

Forward speed, application rate, width of boom, number of nozzles, distance travelled and dose rate changes are all displayed. Error signals inform the driver of a system malfunction. A printer module provides the driver with a complete spray record.

The Agrifutura Dose 500

This system, developed in Sweden, is less sophisticated than the Dose 2000 and is designed to be retro-fitted to smaller sprayers. Dose 500 comprises three water driven pumps and a mixing chamber. Up to three products can be applied via the manually adjusted pumps; whilst dose rates cannot be adjusted on the move, the individual pumps can be switched over to rinsing water thus allowing the pipes to be flushed through and spot treatment of weeds to take place.

The MSR/Ciba-Geigy Agroinject

The Agroinject is a joint development between the German pump manufacturer, MSR, and Ciba-Geigy in Germany. This system is due to be commercially launched in the United Kingdom in the New Year. This system comprises a large single water driven pump with the ability to inject up to four pesticides simultaneously. A suction probe is fitted into each pesticide container and pesticide is withdrawn into a mixing chamber where they meet and are thoroughly mixed with water, before passing out to the booms. The application rate is set before operation, although individual containers may be switched on or off by means of solenoid valves. An in-cab controller monitors and controls the injection system.

INJECTION SYSTEMS UNDER DEVELOPMENT

The Vicon System

The Vicon Injection System comprises a dual tube peristaltic pump with both large and small bore tubes. This allows a wide range of application rates. The pump is driven by a variable speed electric motor. The pesticide is removed from the container by means of a probe via the pump to the inlet side of the main sprayer water pump. The quantity of pesticide being injected can be altered by the speed of the electric motor. The pesticide joins the flow of water and is mixed thoroughly as it passes through the water pump and out to the sprayer boom.

The water pump is an axial piston (swashplate) pump, so that output can be varied according to requirements. The dual tube pump and main water pump can be regulated together. This allows for a change in pump output while maintaining a constant concentration of pesticide in the water. A series of electrically controlled valves allows the operator to immediately stop injecting pesticide and to return unused product back to the container.

AFRC Engineering Application Rate Control System

This system has been developed so that pesticide can be removed from the manufacturer's container and transferred directly to the cylinder.

A probe is placed in the product's original container and pesticide is drawn out via suction created by a piston moving within the cylinder. The piston moves by means of water being withdrawn from one side of the piston. A venturi situated in the sprayer return line, between the water pump and water tank, creates the suction.

Piston direction can be reversed, thus pushing out the pesticide into the mixing chamber situated in the sprayer water line, between the water pump and the boom. The piston is pushed by means of a metering pump which withdraws water from the main water line. Pressure sensors are used to monitor the differences either side of the pump, pump speed and forward speed. The flow rate of water into the cylinder equals the flow rate of pesticide from it.

The flow of clean water through the metering pump reduces the flow rate problems associated with pesticide viscosities and is less harmful to the metering pumps and seals.

The Advantages of Closed Injection Systems.

Closed Injection Systems have several environmental, safety and financial benefits over conventional spray equipment.

Benefits to the Environment

- Only clean water is used in the main sprayer tank so there is no danger of pesticide carryover to non cropped areas or the following crop to be sprayed.

- Water can be withdrawn from a natural water course without fear of suck-back of pesticide.

- There is no risk of spillage of concentrated product during mixing operations at the headland.

- Ease of spot treatment precludes the need for blanket treatment.

- Dose rates can be adjusted on the move to accommodate different levels of infestation, soil types and headlands, which prevents over-application of chemicals.

Benefits to the Operator

- The operator is not exposed to neat chemicals, the parallel development of closed transfer systems will lead to closed injection systems.

- The sprayer is easy to flush and the Distance Remaining feature allows rinsing before leaving the field.

- Nozzle throughput can be checked using clean water.

- The injection system is easily fitted to conventional sprayers.

- Simple controls allow the operator to change dose rates quickly and accurately.

- A simple calibration process allows use of all types of pesticide, from water soluble to wettable powders.

Benefits to the Farmer

- Better use of labour as the operator spends less time calculating, mixing and cleaning.

- Less pesticide wastage as left over chemical can be returned to the store.

- Accurate application by sophisticated electronic metering and precisely calibrated pumps allows cost-effective pesticide usage.

- Thorough mixing of pesticide prevents scorching.

- Reduction of input costs where effective spot treatment can be employed.

Conclusions

As more emphasis is placed on the safer use of pesticides there will be a greater need for direct injection sprayers to avoid operator contamination and environmental pollution. Although the adoption of direct injection closed system sprayers will incur extra costs throughout the farming community, the undisputed advantages will far outweigh the increase in capital costs.

APPENDIX D

PREVIOUSLY PUBLISHED PAPERS

Landers, A.J. (1992). Workrate- a computer program. Spreadsheets in Agriculture. Noble, D.H., and Course, C.P., eds. Harlow: Longman (In Press)

Spreadsheet AL1

Machine Performance Analysis

Purpose: To help the farmer/adviser/student appreciate the effects of changes in the operating parameters when using or choosing farm equipment.

Author: Andrew Landers.

Spreadsheet Name: WORKRATE

AL1.1 Introduction

The computer operator is able to demonstrate how the workrate of an implement will change when parameters such as width and filling time are altered, eg:

a) A farmer may be considering changing from a 12 metre tramline system to an 18 metre tramline system. The effect of changing implement widths - drill, fertiliser spreader and crop sprayer can be clearly seen in the resulting work rates.

b) An adviser can demonstrate that changing crop sprayer boom width will only increase output marginally, whereas altering the logistics - filling time in the field, will increase work rate considerably.

c) A fertiliser representative may use the program to show the effect on work rate of using large half or one tonne big bags to speed up filling the hopper compared with traditional 50kg bags.

d) A farm machinery representative may be trying to convince a farmer that an implement gives a certain output; both parties could use the program to double check their respective queries.

The spreadsheet is displayed at Fig. AL1.1

AL1.2 Input data

The program user needs to enter the following:

	Location	
	Machine Model A	Machine Model B

a) Technical specifications of the implements -

implement width (m)	E9	F9
hopper or tank capacity (kg or litres)	E10	F10
b) Operating parameters -		
forward speed (km/h)	E11	F11
application rate (kg/ha or l/ha)	E12	F12
time taken to transport the implement to the field (min)	E13	F13
time taken to fill hopper (min)	E14	F14
c) The field efficiency (%)	E15	F15

AL1.3 Calculations

Fig. AL1.2 shows all the formulas used to calculate the output values for MODEL A (column E). Corresponding formulas are used to calculate the output values for MODEL B (column F).
The basis of the entries in the cells in column E are as follows:

(a) Area covered per load (ha) $= \dfrac{\text{capacity (kg or l)}}{\text{application rate (kg/ha or l/ha)}}$

ie. E24 = E10 / E12

(b) Filling rate (kg/min or l/min) $= \dfrac{\text{capacity (kg or l)}}{\text{filling time (min)}}$

ie. E25 = E10 / E14

(c) Spot work rate (ha/h) = implement width (m) * forward speed (km/h) / 10

ie. E26 = E9 * E11 / 10

(d) Total time per load (min) = filling time (min) + 2 * transport time(min) +

$$\frac{\text{6000 * area covered by load (ha)}}{\text{spot workrate(ha/h) * field efficiency(\%)}}$$

ie. E28 = E14 + 2*E13 + (6000*E24)/(E26*E15)

(e) Overall work rate (ha/h) $= \dfrac{\text{60 * area covered per load (ha)}}{\text{total time per load (min)}}$

ie. E29 = 60 * E24 / E28

(f) Overall efficiency (%) = $\dfrac{100 * \text{overall work rate (ha/h)}}{\text{spot work rate (ha/h)}}$

ie. E30 = 100 * E29 / E26

(g) Application time per load (min) = $\dfrac{6000 * \text{area coverd per load (ha)}}{\text{spot work rate} * \text{field efficiency (\%)}}$

ie. E34 = 6000 * E24 / (E26*E15)

(h) Application time (%) = $\dfrac{100 * \text{application time per load (min)}}{\text{total time per load (min)}}$

ie. E35 = 100 * E34 / E28

(i) Filling time per load (min) = filling time (min)

ie. E36 = E14

(j) Filling time (%) = $\dfrac{100 * \text{filling time per load (min)}}{\text{total time per load (min)}}$

ie. E37 = 100 * E36 / E28

(k) Transport time per load (min) = 2 * transport time (min)

ie. E38 = 2 * E13

(l) Transport time (%) = $\dfrac{100 * \text{transport time per load (min)}}{\text{total time per load (min)}}$

ie. E39 = 100 * E38 / E28

AL1.4 Sources of data

Useful data regarding capacities, field efficiencies, etc. are obtainable from:-

Bowers W (1981) *Fundamentals of Machine Operation - Machinery Management (2nd edition)*. John Deere Service Publications, Moline, Illinois, USA.

Hunt D R (1983) *Farm Power and Machinery Management (8th edition)*. Iowa State University Press.

Landers A J (1984) *Labour and Machinery Planning*. Unpublished MSC Thesis, Silsoe College, Cranfield Institute of Technology, Bedford

| A || B || C || D || E || F || G |

WORKRATE - A spreadsheet to compare farm machinery outputs
A.J.Landers, Royal Agricultural College, Cirencester, Glos.

INPUT DATA	MODEL A	MODEL B
Implement width (m)	12	18
Capacity (kg or litres)	1500	1500
Forward speed (km/h)	10	10
Application rate (kg/ha or l/ha)	150	150
Transport time (min)	20	20
Filling time (min)	5	5
Field efficiency (%)	75	75

OUTPUT	MODEL A	MODEL B
Area covered per load (ha)	10.0	10.0
Filling rate (kg/min or l/min)	300.0	300.0
Spot work rate (ha/h)	12.0	18.0
Total time per load (min)	111.7	89.4
Overall work rate (ha/h)	5.4	6.7
Overall efficiency (%)	44.8	37.3
COMPONENTS		
Application time per load (min)	66.7	44.4
Application time (%)	59.7	49.7
Filling time per load (min)	5.0	5.0
Filling time (%)	4.5	5.6
Transport time per load (min)	40.0	40.0
Transport time (%)	35.8	44.7

Fig. AL1.1 Machine Performance Analysis Spreadsheet.

```
    |  A  ||  B  ||  C  ||  D  ||               E                |
21                                       MODEL
22  OUTPUT                                 A
23  ------
24  Area covered per load (ha)           E10/E12
25  Filling rate (kg/min or l/min)       E10/E14
26  Spot work rate (ha/h)                E9*E11/10
27
28  Total time per load (min)            E14+2*E13+(6000*E24)/(E26*E15)
29  Overall work rate (ha/h)             60*E24/E28
30  Overall efficiency (%)               100*E29/E26
31
32  COMPONENTS
33  ----------
34  Application time per load (min)      6000*E24/(E26*E15)
35  Application time (%)                 100*E34/E28
36  Filling time per load (min)          E14
37  Filling time (%)                     100*E36/E28
38  Transport time per load (min)        2*E13
39  Transport time (%)                   100*E38/E28
40  ==================================================================
```

Fig. AL1.2 Formulas for Machine Performance Analysis Spreadsheet.